University of Alberta

Towards the restoration of harvested peatlands: Comparisons of harvested and natural peatlands and examination of revegetation techniques

by

Heather Lynne Wind-Mulder ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Abstract

To investigate how to restore harvested peatlands, one harvested site and one neighbouring peatland were studied in central Alberta, Canada (53°33'N, 114°44'W).

Chemical conditions on the harvested site were more similar to a moderate-rich fen site, with relatively high nutrient concentrations (mean annual water chemistry values were 4.9-6.1 pH , 0.26-6.61 mg/L NH_4^+-N, 0.01-0.26 mg/L NO_3^--N, 8.4-15.8 mg/L Ca^{2+}, 2.4-3.9 mg/L K^+, 3.4-5.9 mg/L Mg^{2+}, 3.4-8.5 mg/L Na^+). The natural area had lower chemical concentrations, typical of western Canadian continental bogs. Harvesting removed the ombrotrophic peat, exposing more elemental-rich fen peat. High nitrogen concentrations, aqueous NH_4^+-N and available NO_3-N (1992 means, 6.61 mg/L and 73.6 mg/kg), were significantly reduced during the study period in the harvested area (1995 means, 1.97 mg/L and 17.0 mg/kg).

Water levels in the harvested site were low and variable. The destruction of a functioning acrotelm significantly altered water levels and increased water level fluctuation. With dam installations, water levels increased (mean annual water levels increased by 6-141 cm from 1992-1995, with a mean increase of 34 cm) and scattered flooded pools formed. Rising water levels saturated low lying areas and peat surface level rose (up to 47 cm).

Using surface peatland vegetation, called top spit, is a promising method to revegetate a harvested site. A thinner layer of top spit (1-2 cm) resulted in greater vegetative cover and number of species compared to a thicker application (2-4 cm). Spring application of top spit material resulted in the greatest vegetation cover, while summer application had the highest species richness and highest proportion of peatland species. Rapid collection and application is advised to minimize top spit exposure and dessication. Poor fen top spit was more successful than bog top spit, perhaps due to the fen-like chemical conditions on this site.

Field experiences are reformulated into specific and general restoration recommendations.

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Chapter 1

Introduction

1.1 The importance of peatlands

Peatlands are found throughout the world, but are most common in northern latitudes. The area covered by peatlands worldwide has been estimated at 420 million ha, and probably closer to 500 million ha (Kivinen and Pakarinen 1980). Peatlands are found in areas with a positive water balance, and this interplay of water and land influences the local watershed hydrology. More organic matter is produced annually than is decomposed in these water logged areas, and the organic matter accumulates to form peat deposits.

Peatlands are an important part of the global carbon cycle, with undisturbed peatlands serving as large carbon sinks (Gorham 1991). Peatlands are also storehouses of information. The microfossils and macrofossils that accumulate in the peat deposit can be used as a historical record. Peat cores can be analyzed for successional vegetation studies (historical summary in Fægri and Iverson 1964; qualitative methods outlined in Janssens 1988).

A major component of peatlands is *Sphagnum* moss. It has been estimated that there is more carbon stored in *Sphagnum* biomass than in any other plant (Clymo and Hayward 1982). *Sphagnum* influences carbon sequestration through acidification, oligotrophication, and water level change (Vitt and Kuhry 1992). Through the process of paludification, peatlands can acidify large portions of boreal landscapes. These large areas are potentially available for peat harvesting.

1.2 Peatland use

Peatlands have been used for centuries, but usually in ways that damaged the integrity of the wetland ecosystem. Peatlands have been drained for agriculture, forestry or peat harvesting, especially in Europe. Such countries as Denmark, Poland, Germany, and the Netherlands have less than 10% of their original peatland areas left undrained (Kivinen and Pakarinen 1980; Gorham 1990). Britain has drained close to 70% of its original peatlands for agriculture, while agricultural demands in Poland and Germany have taken over 80% of their peatlands (Kivinen 1980).

Peatlands cover an estimated 170 million ha in Canada (Gorham 1990). While only 1% of this area has been drained, primarily for agricultural purposes, the amount damaged is comparable in size to Britain's entire original area of peatlands (Gorham 1990).

1.3 Development of peatland restoration in Canada

The intrinsic value of peatlands has been acknowledged only in the past few decades, and most specifically in this decade. With the growth of environmental awareness, there is more concern about the dwindling areas of undisturbed peatlands, especially in continental Europe and Britain. There was public outcry and boycotts on peat moss products in Britain, and horticultural peat companies were forced to consider conservation measures in conjunction with their harvesting practices (Carlile 1997). In Germany, legislation was passed to promote the restoration of harvested peatlands (Niedersächsisches Landesverwaltungsamt - Fachbehörde für Naturschutz 1990; Schmatzler 1993).

International environmental awareness on this issue has influenced Canada's horticultural peat industry. Originally, companies were concerned with raising their sales, while governments encouraged job creation and the economic benefits of peat harvesting. For example, the New Brunswick Department of Natural Resources and Energy has organized peat workshops since the 1980s, mainly to promote the expansion of this industry in the province. A number of peat companies formed the Canadian *Sphagnum* Peat Moss Association (CSPMA) in 1988 to promote the use of horticultural peat moss. However, public pressure on the peat industry was increasing in Britain in the 1990s, and CSPMA decided that its members should be proactive in addressing the adverse environmental effects of peat harvesting in Canada.[1] To bring these environmental concerns to the attention of the peat industry, the Canadian *Sphagnum* Peat Moss Association and the Peat Research and Development Centre Inc. in New Brunswick together organized the annual New Brunswick peat moss conference in 1992, with reclamation as the conference theme. At this conference, the CSPMA's Preservation and Reclamation policy was discussed, along with the need for more restoration research (Daigle (ed.) 1992).

Two peatland restoration research groups were being established in Canada, around this time. My thesis work in Alberta was begun in the summer of 1991, under the supervision of Dr. Dale Vitt. Somewhat later, Dr. Line Rochefort at Laval University began peatland restoration research in Québec and New Brunswick, in conjunction with a few other researchers and her graduate students.

These two research groups have held four annual conferences on peatland restoration. These meetings started on a small scale, to review the past year's results and to plan the next field season with the students and professors. These conferences have expanded over the years as interest increased from peat industry members, government officials, and other peatland scientists. The most recent restoration conference at Laval University had attendees from 15 different countries (Anonymous 1996).

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[1] Popular concern for the environmental effects of the use of peat have increased in the mid 1990s in Canada and the United States ("The problem with peat" Garden, Deck & Landscape Planner, Summer 1995; "Peatless Gardening" The Avant Gardener, August, 1995; "For Peat's sake" Canadian Gardening, Oct./Nov., 1995; "Peat moss ponderings" Canadian Gardening, Feb./Mar., 1996).

Government, industry and the scientific community have recognized that changes are needed to manage Canada's peatlands environmentally, in a sustainable manner. As peat is under provincial jurisdiction in Canada, each province has its own legislation and approach to the issue of harvested peat fields. For example in Alberta, industry has led an initiative to investigate measures needed for peatland conservation and development. The Peat Management Task Force, composed of industry representatives, provincial government officials, and peatland scientists, was formed in 1991. The first step of the task force was to obtain an inventory of all the peatland areas in the province. This first phase has been completed and is outlined in the report "Peatland inventory of Alberta Phase 1: Overview of peatland resources in the natural regions and subregions of the province" (Vitt et al. 1996). The second phase of the task force, which is still in process, is to rank all the peatlands according to standard conservation criteria. These criteria will help ensure that certain peatlands will be protected from development. This conservation ranking is currently being finalized and is slated for inclusion in new revised lease laws which the task force is drafting.

Canadian research on peatland restoration has only just begun. Following is a summary of the Rochefort and Vitt labs' discoveries related to peatland restoration, from the past six years.

Revegetation patterns and chemical characteristics of harvested peatlands have been investigated. Studies of the natural revegetation of abandoned harvested peatlands indicate that *Sphagnum* growth is limited and the return to a functioning peatland ecosystem is not occurring (Lavoie and Rochefort 1996; Rochefort unpublished). Harvested sites across Canada have been shown to have variable and elevated nutrient concentrations compared to natural peatlands (Wind-Mulder et al. 1996).

As *Sphagnum* is an important component of peatlands, and natural *Sphagnum* establishment on harvested sites is limited, regeneration experiments using *Sphagnum* were conducted. The ability of *Sphagnum* to regenerate from fragments was explored. In the laboratory, new vegetative shoots were found to develop from all sections of the *Sphagnum* plant (Rochefort et al. 1995a). Depth of the water level was found to significantly affect the growth of chopped *Sphagnum* plants in greenhouse plots, as plots with water levels 5 cm below the peat surface had significantly higher *Sphagnum* recolonizing success compared to plots with water levels 25 cm below the peat surface (Campeau and Rochefort 1996). The tolerance to heat and desiccation of *Sphagnum* fragments was also tested. It was determined that *Sphagnum* fragments can survive up to 14 days without water although desiccation delays the onset of regeneration, and high temperatures (48 hours with temperatures of 30 °C and higher) can kill the *Sphagnum* plants (Sagot and Rochefort 1996).

Sphagnum regeneration was not as successful on the harvested sites compared to the controlled laboratory conditions (Campeau and Rochefort 1996), and thus various field and planting modifications were investigated to enhance field *Sphagnum* re-establishment. Some experiments were also expanded to examine peatland plant mixtures, using the surface vegetative layer of a peatland, called top spit, as the vegetation source. When topography of the harvested bays was altered to create such forms as depressions and mounds, vegetation establishment was found to be more successful in sheltered depressions than on the mounds or on level ground (Ferland and Rochefort in press; Quinty and Rochefort 1997). In another experiment, harvested bays were reprofiled to invert the bays' camber, to create a convex shape parallel to the ditches. Plastic sheets were laid on the bays' slopes to direct precipitation to flow to the centre of the bays where *Sphagnum* fragments were spread. *Sphagnum* establishment success was increased by these measures, compared to *Sphagnum* establishment on leveled bays (Bugnon et al. in press). *Sphagnum* re-establishment was found to improve with companion planting with *Eriophorum angustifolium*. and with a light phosphorus fertilizer (Rochefort et al. 1995b; Rochefort et al. 1995c; Ferland and Rochefort in press). Ground covers have been added to *Sphagnum* fragments and top spit plots, and both shade cloth and a straw mulch have shown increases in vegetation establishment (Rochefort and Bastien submitted; Quinty and Rochefort 1997; Rochefort et al. 1997; Rochefort and Campeau 1997 (summary)).

Although we have learned a lot in the past few years, many questions pertaining to Canadian peatland restoration remain unexplored.

1.4 Comparisons of Canadian and European peatlands

Peatland restoration has been researched in European countries, which adds to our knowledge base. However, not all the techniques and results can be directly applied to Canadian harvested sites, due to several significant differences in the peatlands of the two areas. These differences include climate, species composition and types of human inputs.

Climatic conditions are different in Europe and Canada. For example, Alberta has a continental climate, with drier summers and harsher winters than the more oceanic Britain, with its wetter summers and milder winters.

Peatland species differ in the two continents. Also, Europe has some different problem species such as the weedy *Molinia caerulea*. *Molinia caerulea* invades harvested sites, and hinders *Sphagnum* recolonization due to *Molinia's* high evapotranspiration rate and its drying effect on harvested sites (Schouwenaars 1992).

European peatlands are exposed to higher concentrations of air and water pollution than Canadian peatlands. *Sphagnum* species are sensitive to air pollution, and nutrient eutrophication in Europe is a problem for the normally nutrient limited systems of peatlands. Ferguson et al. (1984) and Press et al. (1986) documented that atmospheric pollution reduced the growth of transplanted *Sphagnum* species and has probably led to the overall decline of *Sphagnum* moss in polluted areas of Britain. In Canada at the Experimental Lakes Area, Bayley et al. (1987) found that additions of H_2SO_4 and HNO_3, general components of acid rain, actually increased *Sphagnum* growth. Further research in Sweden showed that *Sphagnum* in areas with low atmospheric pollution responded to nitrogen additions with increased growth, while areas which were already saturated with long term, high concentrations of nitrogen deposition had no increase in *Sphagnum* growth (Aerts et al. 1992). These studies show that the differing concentrations of pollution and eutrophication affect *Sphagnum* growth in Canada and in Europe differently.

Most Canadian peatlands occur in places with low population densities, whereas in Europe, population densities are often high and in close proximity to the remnants of disturbed peatlands. Restoration plans can be restricted by adjacent private property owner's concerns. Often long term management measures are necessary, to restrict possible effects to neighbouring areas.

In Europe, peatlands have been influenced and damaged by humans for centuries, and large areas of peatland have been drained. In Canada, human influence has been relatively recent.

Canada's peat industry is quite young and Canada has a very small portion of its peatlands being harvested, just 0.009% or 16 000 ha (Hood 1991). Most of the horticultural peat harvesting has occurred in the past 60 years. Only recently have areas become available for restoration as individual harvested fields are exhausted of economically harvestable, *Sphagnum* bog peat. Peat industry members have also realized that environmental controls are necessary, and restoration measures should be planned even before new sites are opened. Provincial governments in New Brunswick and Alberta have recognized the need for guidelines and legislation to protect peatlands, and for the restoration of harvested peatlands.

1.5 Natural restoration of harvested sites

To discuss the need for the restoration of harvested peatlands implies that human intervention is necessary for these sites to become functioning peatland ecosystems once again. Why is human intervention necessary? Why not just leave the sites to naturally revegetate?

Abandoned harvested sites have low revegetation cover, even for decades after abandonment. Famous et al. (1989) and Nilsson et al. (1990) conducted surveys of the natural recolonization of abandoned peatlands in the US and Canada, and found that these sites had very little natural revegetation, especially on vacuum harvested sites. Moreover, the vegetation that did establish was not typical peatland vegetation, but was mostly comprised of weedy upland species.

The most common method of peat harvesting in Canada is vacuum harvesting which involves the opening and draining of large areas of peatlands, for extensive periods of time. Although other methods of harvesting are still disruptive, block cutting and other digging methods tend to focus peatland disturbance in smaller areas for shorter time periods. With block cutting, peat is harvested by digging a successional series of trenches along the peatland, with less effort to significantly lower water levels. As an older trench is depleted of its usable peat, harvesters move over to start a new trench. Surface peatland vegetation from the top of the new trench is often tossed into the old trench, thereby aiding the recolonization in the trench by *Sphagnum* and other peatland plants. Vacuum harvesting is more economical in Canada, and therefore, more widespread, but it leaves a harsh environment for peatland restoration.

Removal of surface peat during commercial harvesting affects the hydrology of the site. The original vegetation surface and upper bog peat layers which formerly composed the acrotelm are removed with harvesting. Removal of the acrotelm layer destabilizes the regularly high water level. Water levels are often extremely low and variable in harvested sites, which reduces the moisture and hinders recolonization.

Removal of the peat layers also affects the chemical conditions of the peatland surface. Peat layers formed during earlier successional stages of the fen to bog successional gradient are exposed with harvesting. In continental areas for example, the development of peatlands normally proceeds along a nutrient gradient from mesotrophic rich fens, to *Sphagnum*-dominated poor fens, to oligotrophic bogs (Kuhry et al. 1993). The earlier successional peat has relatively high nutrient concentrations, lower acidity and higher alkalinity concentrations. These changes in nutrient conditions affect peatland vegetation re-establishment. Peatland species are highly sensitive to these chemical factors (Vitt and Chee 1990), and most are limited in their distribution by one or more of these parameters (Gignac et al. 1991).

Peat harvesting removes all of the viable seed bank (Salonen 1987). Due to the usual large size of the affected areas, diaspores (seeds, plant fragments) are not always nearby to allow natural recolonization of the site once harvesting activities have ceased (Nilsson et al. 1990). Wind erosion is also high on these large, open expanses of harvested peatlands, which also limits the re-establishment of peatland plants (Famous et al. 1989).

Low water levels, altered chemical conditions, lack of a seed bank, and high wind erosion inhibit moss recolonization and establishment. Moss species are an important component in a functioning peatland due to their dominance and unique characteristics. A living carpet of moss has a high water holding capacity and a low bulk density which helps in the formation of the water level stabilizing acrotelm. Thus establishment of the moss mat is essential, however, even more significant is the establishment of a ground cover of *Sphagnum*. *Sphagnum* can acidify their surroundings, aiding in the succession from rich fen to bog, in the persistence of a bog ecosystem, and the sequestration of carbon through peat accumulation. As carbon sequestration in the original bog ecosystem is the ultimate goal of restoration, and *Sphagnum* species are necessary for a functioning restored bog, restoration measures must aid in the establishment and success of *Sphagnum* growth. Since the harsh factors listed above make harvested sites inhospitable to revegetation, intervention is necessary for the re-establishment of *Sphagnum* and other peatland species on these harvested sites.

1.6 Restoration versus revegetation

It has been stated that peatlands are a valuable ecosystem and that harvested peatlands need assisted restoration measures, but what is meant by "restoration"?

To restore an ecosystem is to renew, repair or reconstruct it to its original state. A peatland is a dynamic integration of floral, faunal, microbiological, hydrological, and chemical components which work together holistically. To restore a harvested peatland would be to recreate this functioning system, such that the site would once again form and accumulate peat, and thus again sequester carbon. A restored site would be self sustaining without further human input, and resilient to outside disturbances.

To re-establish vegetation cover on a harvested peatland, revegetation, is an important step toward restoration, helping to recreate part of the peatland structure. Yet revegetation must be qualified. Although the establishment of peatland trees and ericaceous shrubs alone would be considered revegetation, the function of accumulating peat and sequestering carbon would not be re-instated in the peatland. For this function, establishment of a *Sphagnum* mat is necessary. The growth of *Sphagnum* would initiate the accumulation of peat, and the ombrotrophication of the system. Thus revegetation with *Sphagnum* is one step toward a carbon sequestering system. Further measures may be needed to ensure that a full biological community establishes on a restored peatland, and that ecological peatland processes are re-instated.

How does one start to restore a harvested peatland site? In Canada, we have little knowledge of how harvested and natural peatlands differ. Investigations into restoring these harvested sites are few in number and very recent, especially in North America. Even basic questions, such as how are harvested sites chemically and hydrologically different from undisturbed peatlands, have received little study. Thus to begin to restore a harvested peatland, the chemical and hydrological characteristics of both harvested and undisturbed sites need to be investigated. Since water levels are low in ditched harvested sites, such rewetting measures as dams are needed. As natural revegetation of peatland species is scarce on harvested sites, measures to re-establish peatland plant cover are necessary. Restoration measures need to be tested, to further refine our knowledge of restoring peatland systems and to improve our restoration techniques.

1.7 Questions addressed in this dissertation

As our desire to restore harvested peatlands is ahead of our knowledge of the best methods for restoration, investigations are necessary to fill the gaps. This dissertation addresses some of these knowledge gaps.

The first objective of this study was to investigate how a harvested peatland compares to a neighbouring, unharvested peatland in central Alberta. Preliminary work began at Seba Beach, Alberta in the summer of 1991, and harvesting of the site ceased that fall. Analyses of the peat and water chemistry were conducted on the sites from 1991-1995. Water levels were measured to examine the hydrology of the sites.

The second objective was to investigate revegetation methods to accelerate peatland plant establishment on harvested sites. Various revegetation experiments were carried out to explore techniques to re-establish vegetation. As revegetation of *Sphagnum* is key to restoring peatland integrity, revegetation experiments focused on establishing a good ground cover of *Sphagnum* moss, in conjunction with other peatland plants.

This dissertation is divided into six chapters, addressing these two objectives. Chapters 2-4 address the differences of harvested and natural peatlands, while Chapter 5 focuses on revegetation experiments. Chapter 6 summarizes the conclusions and gives practical applications for restoring harvested peatlands.

In chapter 2, I examine the spatial variation in chemistry in harvested sites. In this chapter, the peat and water chemistry of the harvested site in Alberta is compared to three other harvested sites in eastern Canada, and with neighbouring undisturbed peatlands. This chapter is based on a paper written in conjunction with Line Rochefort and Dale Vitt (Wind-Mulder et al. 1996). To characterize the harvested sites, the following questions are asked.

- What are element levels and nutrient conditions of the harvested sites?
- How does the peat and water chemistry of post-harvested sites compare to natural peatlands?
- How has harvesting affected the chemical conditions?
- To what peatland successional stage are the harvested sites most similar?
- How do the chemical conditions of the harvested sites affect restoration plans?

In chapter 3, I examine the chemical variation of one site over a temporal five year period, after harvesting ceased. In this chapter, the water and peat chemistry of the Seba Beach harvested peatland is compared to the neighbouring natural area. The subsequent questions are investigated.

- How has peat and water chemistry been altered on the harvested site?
- Have chemical conditions changed during the study period of five years?

In chapter 4, I examine how water levels have varied since harvesting ceased and restoration procedures began. In this chapter, water levels monitoring on the harvested and undisturbed Alberta sites over the years 1992-1995 is used to characterize and compare the hydrologies of the two areas. These questions are examined.

- Were water levels in the harvested site similar to water levels in the neighbouring natural peatland? Were the annual mean water levels and annual amplitudes similar between the two areas?
- How have water levels reacted to the partial removal of the peat deposit with harvesting?
- Did the water levels change over the four year study period? Were water levels in the harvested site stabilized, aided by such rewetting measures as the installation of a dams?
- How could water levels be improved on harvested sites?

In chapter 5, I examine methods of establishing *Sphagnum* and peatland vegetation on a harvested site. This chapter focuses on top spit revegetation experiments on the Seba Beach harvested peatland. Top spit, the live layer of surface vegetation of a peatland, is examined as source material for revegetating areas on the harvested field. Several experiments were set up to answer the following questions.

- Is the use of top spit material a feasible restoration procedure for this harvested peatland?
- When is the best time to spread top spit on the site?
- How thick should the top spit application be? Does more top spit material result in more vegetation?
- Would a second application of top spit significantly increase levels of revegetation compared to a single application of top spit? Would this two step process specifically increase moss growth?
- Does bog or poor fen top spit revegetate more successfully on the site?

- Does a straw covering over the applied top spit increase vegetation cover?
- Which treatments result in the highest species diversity and the greatest vegetation cover? Did high species diversity coincide with high vegetation cover?
- What types of plants occur on the top spit plots? Did plants other than peatland plants establish on the top spit plots?

Lastly, the concluding chapter summarizes the dissertation results and how they relate to peatland restoration. A restoration plan for the Seba Beach site is outlined, as well as general restoration guidelines. These practical applications of this dissertation should be incorporated into pre-development plans of peatland sites, and included in the initiation of government leasing agreements.

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Chapter 2

Water and peat chemistry comparisons of natural and post-harvested peatlands across Canada and their relevance to peatland restoration

A version of this chapter has been published.

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Ecological Engineering 7: 161-181.

2.1 Introduction

Peatlands, with their large carbon deposits, are a useful source of peat which can be used as a soil amendment, a fuel source, and as absorbent material. In Canada, horticultural use of peat consumes an average of 750 metric tons of peat annually (Keys 1992). Vacuum harvesting is now the most common harvesting method and affects large areas over long periods of time. Removal of peat layers during commercial harvesting exposes peat layers formed during earlier successional stages of the fen to bog successional gradient and affects the chemical and hydrological conditions of the peatland surface. The development of peatlands normally proceeds along a nutrient gradient from mesotrophic rich fens, to *Sphagnum*-dominated poor fens, to oligotrophic bogs (Kuhry et al. 1993). Potential revegetation of sites after abandonment is expected to be affected by these new conditions.

Peat removal with harvesting changes not only the chemical characteristics, but also removes much of the viable seed bank (Salonen 1987). Due to the usual large size of the affected areas, diaspores (seeds, plant fragments) are not always nearby to allow natural recolonization of the site once harvesting activities have ceased (Nilsson et al. 1990). Water levels are low and wind erosion is high, further hindering recolonization of peatland plants (Famous et al. 1989). Left alone, these sites are often barren for decades after harvesting (Nilsson et al. 1990). Intervention is necessary to aid in the re-establishment of peatland species on post-harvested sites.

Examination of how chemical conditions in post-harvested peatlands compare to natural peatlands has not been carried out in North America. Analysis of the peat and water chemistry of harvested and neighboring undisturbed peatlands allows the changes in nutrient status, elemental concentrations, and successional peatland type to be determined. Knowledge of the chemistry of the post-harvested sites is critical to restoration efforts, as plant species that can be potentially used in revegetation have distinct tolerances to surrounding chemical and hydrologic factors (Sjörs 1950, Sjörs 1952, Gignac et al. 1991a). Thus appropriate peatland plant species can be chosen for restoration. In addition, chemical studies would indicate if any ameliorative measures such as fertilization are necessary. These studies also indicate the potential effects of stopping harvesting at different peat depths.

In this paper, we compare the chemistry of post-harvested and associated natural peatlands of four sites across Canada, reflecting the provinces most active in horticultural peat harvesting (Alberta, Québec, and New Brunswick), in order to determine the effects of peat harvesting.

2.2 Site descriptions

Before harvesting procedures commenced, the four sites surveyed in this study were bogs. The sites are located along an east-west transect across Canada (Figure 2-1). Tree cover increases from the east coast to the western interior in the natural, undisturbed peatlands. The yearly temperature curves are similar among the four sites, while the amount of precipitation varies (Figure 2-2). The sites in Québec and New Brunswick receive more precipitation. The two Québec sites have precipitation more evenly distributed throughout the year.

2.2.1 New Brunswick - Maisonnette

The Maisonnette peatland is located on the Acadian Peninsula, near Caraquet (47°49'N, 65°02' W; Figure 2-1). This wetland is classified as a Maritime Atlantic Boreal Peatland (National Wetland Working Group; NWWG 1986). The mean annual temperature for the area is 3.3 °C, with total annual precipitation of 722 mm, of which approximately 50% falls as rain (Figure 2-2). This coastal raised bog has dimensions of 3.9 km by 2.0 km (541 ha). Originally, the bog was covered by ericaceous shrubs and *Sphagnum*, with *Picea mariana* (black spruce) and *Larix laricina* (larch) occurring near the margins (nomenclature follows Anderson (1990) for *Sphagnum* mosses and Scoggan (1978) for vascular plants).

Approximately 339 ha have been prepared for horticultural peat production by Fisons-Western Ltd. (currently Sun Gro Horticulture Canada Ltd.) using the vacuum harvesting method. Harvesting of the site ceased in 1992, just prior to restoration work. The restoration site covers an area approximately 2.16 ha, or 0.6% of the area in production. A peat depth of 0.4 to 1.2 m was left on the site after harvesting. To recharge the site with water, the main perimeter ditch was filled with bulldozed peat, as were four secondary channels in August 1992.

2.2.2 Eastern Québec - Rivière-Ouelle

The Rivière-Ouelle peatland is located approximately 150 km northeast of Québec City (47°27' N, 69°56' W; Figure 2-1). Harvested for horticultural peat by Tourbières Lambert Inc., this peatland is 1535 ha in area. This eastern Québec peatland is an Atlantic Boreal wetland (NWWG 1986). The area surrounding this peatland has a mean annual temperature and precipitation of 4.2 °C and 967.4 mm, respectively (Figure 2-2). Of the precipitation, 66% occurs as rainfall. Peat harvesting of this bog was started in the 1930's using the block-cut method. Today, nearly half of the peatland surface is being extracted for horticultural peat with the vacuum harvesting method.

Restoration experiments at the Rivière-Ouelle peatland began in the summer of 1993 and took place on three vacuum harvested bays, 3 ha in total, that were abandoned approximately ten years ago. A depth of 1 m of peat remains at the restoration site. The peat substrate has only been sparsely colonized by plants, with plant cover of less than

10%, consisting mainly of small *Betula papyrifera* and *Eriophorum* spp. To rewet the site, all secondary ditches adjacent to the restoration bays were blocked.

2.2.3 Central Québec - Sainte-Marguerite-Marie

The Sainte-Marguerite-Marie peatland is located in central Québec near Lac Saint-Jean (48°47' N, 72°10' W; Figure 2-1). This peatland is classified as a Low Boreal peatland (NWWG 1986). This area has a mean annual temperature of 1.7 °C, with annual precipitation of 905.7 mm, of which 71% falls as rain (Figure 2-2). The total area of the peatland is 4312 ha. The undisturbed ombrotrophic areas are dominated by *Sphagnum angustifolium, S. capillifolium, S. fuscum*, and *S. magellanicum*, ericaceous shrubs and some interspersed *Eriophorum angustifolium, Picea mariana*, and *Larix laricina*.

The experimental site is located on a series of bays within an area of 60 hectares, where peat harvesting stopped in 1991. The peat was extracted by a block cutting method by Fafard et Frères Ltée for the production of *Sphagnum* based absorbent board. A peat depth of 2.5-3 m remains on the site and the surface is fibric-mesic peat. The secondary drainage channels of the experimental bays were blocked in late April 1992 to allow rewetting of the surface.

2.2.4 Alberta - Seba Beach

The Seba Beach peatland is located about 130 km west of Edmonton (53°33'N, 114°44'W; Figure 2-1). This peatland is classified as a Continental Mid-Boreal peatland (NWWG 1986). The area has a mean annual temperature of 2.4 °C and annual precipitation of 528.8 mm, considerably less than the three eastern sites (Figure 2-2).

Originally this peatland was covered by bog and poor fen vegetation dominated by *Picea mariana, Sphagnum fuscum*, and scattered *Larix laricina*. This site was first opened in 1975 to harvesting by dredging. In 1980, another peat harvesting company, now Sun Gro Horticulture Canada Ltd., leveled, drained, and then vacuum harvested the area. The restoration site is approximately 16 hectares in area, 0.02% of the area presently being harvested. Surface height of the peat is highest in the northeastern corner sloping to the southwest corner, with drainage southwestward. Peat depth ranges from 0.73 m at the northern end, deepening at the southern end to over 4 m.

In order to raise the water level, a dam was constructed in the southwest corner in the fall of 1991, when peat harvesting ceased. In early 1992, the lower areas of the southern end of the field were flooded, with the northern end of the site staying relatively dry. Beginning in 1992, *Carex* spp. and meadow-annuals invaded the wetter areas while much of the drier areas remained vegetation free.

2.3 Methods

2.3.1 Water chemistry

Water samples were collected from various locations within the post-harvested fields and from the neighboring undisturbed peatlands for comparative measures. Surface water pH was measured in the field or in the lab, from samples obtained from pools, ditches, or from within water level pipes. Surface water samples, with the exception of the Alberta site, were first filtered using a 0.45 µm cellulose acetate filter, then measured for conductivity values with corrections for temperature at 20 °C and hydrogen ions (Sjörs 1952). Surface water nutrients were analyzed by the Department of Zoology at the University of Alberta, the Peat Research and Development Centre in Shippagan, New Brunswick, or the Centre de Recherches minérales, Ministère de l'Énergie et des Ressources (Gouvernement du Québec), in Sainte-Foy, Québec. Water samples were stored in 1-L Nalgene polyethylene bottles for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total phosphorus (TP), and NO_3^--N analyses. Water samples for NH_4^+-N analyses were stored in 250 mL polystyrene flasks or polyethylene bottles. Samples for Na^+, K^+, Ca^{2+}, and Mg^{2+} were filtered through a prewashed Whatman GF/C filter, stored at 4°C, and analyzed on an atomic absorption spectrometer (Perken-Elmer, model 3300 or Varian 1475). Analyses of Cl^- and SO_4^{2-} were conducted by ion chromatography with a Waters chromatographic system. Samples for TP were filtered under low pressure (-50 kPa), through a 250-µm Nitex net and transferred to culture tubes (Menzel and Corwin 1965 modified by Prepas and Rigler 1982). These samples were analyzed colormetrically on a Milton Roy Spectronic Spectrometer or a UV/vis LKB Urtrospec II. After filtration through a prewashed 0.45-µm HAWP Millipore membrane filter, nitrate was determined by the cadmium-copper reduction method of Stainton et al. (1977) or using ionic chromatography with a Waters chromatographic system. Ammonium samples were analyzed by Solórzano's (1969) phenolhypochlorite method as modified by Prepas and Trew (1983) or by steam distillation with a Kjeltec 1002 Distillation System. For more detailed methods by site, see Appendices 1 and 2.

2.3.2 Peat chemistry

Peat samples were collected from 0-5 and 1-5 cm profiles from the harvested peat surfaces and from 1-5 and 10-15 cm profiles in the natural areas. Samples were stored in polyethylene bags at a cool temperature until analysis. Peat pH was analyzed by one of three ways: 1/ by using a 1:2 ratio of fresh peat and double distilled water using methods from the Department of Soil Science at the University of Alberta (1990), 2/ by measuring mixtures of 3 g of air dried peat with 50 mL of 0.01 M $CaCl_2$, or 3/ by saturating the samples with distilled water, filtering the slurry with an Whatman #1 filter, and measuring pH on the filtrate. Peat electrical conductivity analyses were conducted using the same ratios or using a 1:10 ratio of fresh peat and distilled water. Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs

(1952). Surface peat samples were analyzed for the elements P, Mg, Na, K, and Ca by one of three ways: 1/ by dry ashing samples at 470 °C, acid digesting the ash with 6 mL 1.5 N HCl and 1 mL concentrated HNO_3, and analyzing the filtered samples by inductively coupled plasma spectrophotometry, 2/ by displacing the cations by agitating the sample in a solution of 1N ammonium acetate (CH_3COONH_4) at pH 7 and then analyzing the filtrate by atomic absorption spectrophotometry, or 3/ by saturating the peat with distilled water and measuring the filtrate, using atomic absorption spectrophotometry. Total S was analyzed by one of two ways: 1/ by dry ashing samples at 470 °C, acid digesting the ash with 6 mL 1.5 N HCl and 1 mL concentrated HNO_3, and analyzing the filtered samples by inductively coupled plasma spectrophotometry, 2/ by oxidizing sulfur to sulfate and measuring the gas by LECO S analyzer (De Blois 1991). Available nitrate was extracted by using 1:20 ratio of air-dry ground peat and 2N KCl, mechanically shaken for 30 minutes and analyzing the filtrate using a technicon autoanalyser and the Industrial Methods 158-71 W/B, December 1972. Available ammonium was extracted by one of two ways: 1/ by using 20:1 ratio of air-dry ground peat and 2N KCl, mechanically shaken for 30 min and analyzing the filtrate using a technicon autoanalyser and the Industrial Methods 96-82W, April 1983, respectively, or 2/ by steam distillation of 10 g samples placed in 100 mL of double distilled water. Samples were analyzed by the author, the Department of Zoology at the University of Alberta, the Peat Research and Development Centre, or the Centre de Recherches minérales, Gouvernement du Québec, Ministère de l'Énergie et des Ressources. For more detailed methods by site, see Appendices 3 and 4.

Although some methods differed between sites for water and peat chemistry analyses most analyses were comparable, and discussion also focused on how harvested and neighbouring natural peatlands compared. How differing methods may have affected result comparisons is dealt with further in the Appendix 5.

2.4 Results

2.4.1 Natural areas - Water and peat chemistry

Hydrochemical analyses of the natural areas showed a general trend of lower elemental concentrations with less variation than the harvested site values (Tables 2-1 and 2-2). The natural areas had pH values of the surface water ranging from 3.6-4.0 (Figure 2-3A, white bars). Total phosphorus, NH_4^+-N and NO_3^--N, had mean annual ranges of <0.15-5.7 µeq/L, <3.6-112.1 µeq/L, and <3.6-4.3 µeq/L, respectively (Figure 2-3A, white bars). Sodium and Cl^- increased in concentration in the surface waters toward the coast with the continental areas of central Québec and Alberta having 13-34 µeq/L and 3-13 µeq/L, respectively compared to New Brunswick and eastern Québec with 122-718 µeq/L for Na^+ and 91-190 µeq/L for Cl^- (Figures 2-3A and 2-3B). Potassium had a very narrow range of 5-7 µeq/L in the natural areas, while Ca^{2+}, Mg^{2+} and SO_4^{2-} had somewhat wider ranges, without apparent geographic trends (Figure 2-3B).

Although data for peat chemistry is less complete than that for water chemistry, some trends are apparent. The surface peat was acidic with mean annual pH ranging from 2.7-4.2 (Figure 2-3A, white bars). Total phosphorus and NH_4-N concentrations were higher than the low values for NO_3-N. The maritime influence on Na concentrations in the peat was not as obvious as in the water, although the eastern sites had higher concentrations than the site in Alberta (Figures 2-3A and 2-3B, white bars). Higher concentrations of K were also present in the east, while the western site had higher concentrations of Ca than the eastern sites. No consistent trends were found for Mg and S in the surface peat of the natural areas (Figure 2-3B).

2.4.2 Harvested areas - Water and peat chemistry

Although some geographical variation in chemistry was present in the natural areas, most elements had limited variation across the four sites. The four harvested areas had more variation than the natural areas for every element in both surface water and peat (Tables 2-3 and 2-4, and Figures 2-3A, 2-3B, and 2-3C). Mean annual surface water pH varied from 3.7-6.2, with values being higher than pH 4 in eastern Québec and Alberta (Figure 2-3A, solid bars). Mean annual total phosphorus ranged from <1.9-17.9 µeq/L, with the Alberta sites having the highest concentrations (Figure 2-3C, solid bars). Ammonia-nitrogen ranged from 13.5-505.7 µeq/L, with the highest values occurring in New Brunswick, while NO_3^--N ranged from 0.7-42.1 µeq/L (Figure 2-3C).

As in the natural areas, annual means of Na^+ and Cl^- were higher in the harvested areas of New Brunswick and eastern Québec than in the more continental sites. Most of the Na^+ means and all of the Cl^- means were higher in the harvested areas than the corresponding natural areas. In New Brunswick and eastern Québec, annual means for Na^+ and Cl^- ranged from 281-479 µeq/L and 131-404 µeq/L, respectively while the lower concentrations in central Québec and Alberta ranged from 18-211 µeq/L and 16-29 µeq/L, respectively (Figures 2-3A and 2-3B, solid bars).

The harvested areas had greater variation in K compared to the narrow ranges present in the natural areas. Calcium, Mg^{2+} and SO_4^{2-} had wider ranges than K^+. The Alberta harvested site had the highest annual means for Ca and Mg, while central Québec had the lowest SO_4^{2-}, while the other harvested sites had means between 202-257 µeq/L (Figures 2-3B and 2-3C, solid bars).

Comparisons of water samples collected from ditches in harvested fields and water samples from surface hollows or from within water level pipes were made at two of the harvested sites. Although the central Québec ditches and surface hollows varied only slightly, the water from the Alberta harvested site showed large differences. Water from pipes had higher concentrations of Na^+, NH_4^+-N, NO_3^--N, and total P, than that taken from the ditches (Figure 2-4).

Surface peat chemistry of the harvested areas had similar trends to that found in the natural areas. The harvested sites had higher peat pH, with annual means ranging from 2.9-4.5, with the highest values present in Alberta (Figure 2-3A, solid bars). The maritime influence of high Na concentrations in the eastern sites was not apparent in the harvested peat, as the Alberta site had the highest Na concentrations (Figure 2-3B, solid bars) [1]. Potassium ranged from 95-332 mg/kg, with Alberta having the highest annual means (over 250 mg/kg). In the harvested areas, Ca annual means ranged from 780-7952 mg/kg, with the highest values in Alberta, and similar to those of the natural areas. As in the natural areas, Mg and S in the peat did not show any consistent trends. Total phosphorus annual means of peat were similar to those of the natural areas, while NO_3-N annual means of peat were higher in the harvested areas, and NH_4-N annual means were similar or higher than values in the natural areas. In Alberta, nitrogen concentrations appear to be related to soil moisture, as wetter areas of the harvested site had higher NH_4-N concentrations and lower NO_3-N concentrations, while drier areas had higher NO_3-N concentrations and lower NH_4-N concentrations (Figure 2-5).

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[1] Dry ashing, and acid digestion techniques were used to give the element content of the Alberta peat samples, while the eastern sites were analyzed using exchangeable cation techniques (see Appendix 5). Literature values for exchangeable:total bases ratio for Ca, K and Mg were used to convert the Alberta values, but few differences were found (Appendix 5). As an exchangeable:total bases ratio for Na is not known, it is unclear how the high Na concentrations at the Alberta site truly compare to the eastern sites. Perhaps the maritime influence of high Na concentrations in the eastern sites would have been apparent in the harvested peat if exchangeable Na had been measured at the Alberta site.

2.5 Discussion

2.5.1 Water chemistry

Removal of the peat surface with harvesting affected the water chemistry of the harvested sites with the exposure of the underlying peat layers. Harvested areas had 2 to 20 times the variation in chemical characteristics than the natural peatlands. In the New Brunswick and eastern Québec harvested peatlands, higher concentrations of aqueous K^+, Mg^{2+}, and SO_4^{2-} indicate that these sites most resemble poor fen chemical conditions, and are presently not typical of bogs. Water from the harvested area in Alberta was more similar to a poor or moderate-rich fen (Vitt and Chee 1990), with higher values of pH, Ca^{2+}, Mg^{2+}, and K^+ than the other three harvested, eastern peatlands. The central Québec harvested site had the least amount of surface peat removed, and chemical concentrations in the water that most closely resemble the chemical conditions of natural North American bogs (Gorham et al. 1985).

The water chemistry of the central Québec harvested site was similar to that of a bog, while the other three harvested sites had fen chemistry characteristics. Yet all of the harvested sites had nutrient concentrations of NH_4^+-N and NO_3^--N higher than neighboring natural areas and higher than values recorded from other undisturbed peatlands (Figure 2-3B and see references in Table 2-5). Possible reasons why the aqueous NH_4^+-N and NO_3^--N values were higher in the post-harvested sites include: 1/ Values of pH were higher in three of the post-harvested sites than in the natural peatlands, and may allow more nitrifying bacteria to grow (Dickinson 1983). 2/ Drier conditions in harvested areas during the sampling periods may have favored more biological activity of aerobic microbes (Lähde 1969), and higher numbers of nitrifying bacteria (Waksman and Stevens 1928, Zimenko and Misnik 1970, Dunican and Rosswall 1974), thus more organic nitrogen could be mineralized (Heikkinen 1990). 3/ The low (or nonexistent) vegetation cover on the harvested fields may have permitted higher nitrogen concentrations to remain available, due to lack of nitrogen consumption.

Nutrient concentrations of aqueous NH_4^+-N, NO_3^--N and total P in the Alberta harvested area ditches decreased in 1992 and 1993 from the high 1991 concentrations first recorded. The ditches in the Alberta site have increased in vegetation and algal cover since harvesting ceased in 1991, while the areas around the water level pipes on the harvesting bays still have little vegetation cover. The subsequent lower nutrient concentrations of NH_4^+-N, NO_3^--N and total P in the ditches may be a result of vegetation consumption of these nutrients, while these nutrients are not consumed in the harvested expanses. The ditch nutrient concentrations perhaps suggest how revegetation may affect nutrient chemistry. The comparisons between the ditch and surface pit samples from central Québec showed little difference, however this site had low vegetation cover on the harvested bays as well as in the ditches.

2.5.2 Peat chemistry

Peat researchers, such as Mörnsjö (1968), Lähde (1969), Sillanpää (1972), Damman (1978), Hemond (1980), and Clymo (1983, overview), have outlined the vertical distribution of elements in undisturbed bogs. Biological activity of *Sphagnum* causes larger concentrations of K and P in the surface layer, with decreasing concentrations with increasing depth (Mörnsjö 1968, Lähde 1969, Damman 1978, Hemond 1980). Concentrations of K in the surface peat were higher in the natural areas of eastern and central Québec than the corresponding harvested areas. The lower concentrations in the harvested areas in the east (poor fens) indicate that the higher concentrations of these elements in the original surface peat were removed with harvesting and were not replenished due to the lack of biological activity. In Alberta, the concentrations of K were similar in both harvested and natural areas, suggesting a higher nutrient status of the now exposed moderate-rich fen peat in the harvested area (Vitt and Chee 1990).

Magnesium and Ca decrease with increasing depth, possibly due to changes in the ion capacity of the peat and humification (Lähde 1969, Hemond 1980), although Damman (1978) recorded an increase in Mg concentrations with increasing depth. For the harvested site that is most similar to bog chemical characteristics (central Québec), concentrations of Mg were lower than the neighboring natural area while Ca values were similar in both areas. For the fen-like harvested peatlands of eastern Québec and Alberta, Mg and Ca were higher in the harvested than the natural areas and this is probably due to the exposure of more ion rich fen peat with harvesting.

Sodium has the highest concentration in the top 15 cm, and is leached from the top layers of a peat deposit (Damman 1978, Clymo 1983). Lower concentrations of Na in the harvested peat of eastern and central Québec indicate that the higher concentrations of sodium, normally found at the surface of undisturbed peatlands, were removed with harvesting. The concentrations of Na in the Alberta harvested site were higher than the natural area concentrations, possibly due to the exposure of moderate-rich fen peat (Vitt and Chee 1990).

Conductivity and pH have been shown to increase with increasing depth in a peat deposit (Mörnsjö 1968). Peat pH and conductivity were higher in all four harvested areas. The less extensive peat removal in central Québec resulted in only a minor increase in peat pH, while the removal of the bog peat with harvesting at the other three sites revealed the more element rich and less acidic fen peat.

Nitrogen concentrations have been documented to remain low throughout bog peat profiles (Damman, 1978, 1988) yet harvested sites had higher than usual concentrations of NH_4-N and NO_3-N in the surface peat, and more variation in values (Figure 2-3C and Table 2-6). While Salonen (1994) documented ranges of 3-58 mg/kg for NO_3-N and 3-45 mg/kg for NH_4-N of harvested peatlands in Finland, our Canadian sites had more variation with 14-1900 mg/kg NO_3-N and 0-900 mg/kg NH_4-N. As suggested above, these higher concentrations of NO_3-N and NH_4-N in the post-harvested peat may be due to a variety of factors including increased pH, aeration, microbial activity, and low vegetation cover. Evidence that moisture levels affect nitrogen concentrations was present in Alberta, where wetter areas of the harvested site had higher NH_4-N concentrations and lower NO_3-N concentrations, while drier areas had higher NO_3-N concentrations and lower NH_4-N concentrations. Zimenko and Misnik (1970) noted this same trend in which field sites with lower water levels had higher concentrations of nitrate and nitrifying bacteria, and lower concentrations of ammonia and ammonifying bacteria. Salonen (1994) noted a correlation between particle size and the prominent form of nitrogen in harvested peatlands. Higher NO_3-N concentrations were found in peats with larger particle size, while higher NH_4-N soils had smaller particle size. Other laboratory research (Koerselman et al. 1993) showed that higher water levels resulted in higher concentrations of ammonium release in peat soils, while nitrate release was not significantly affected by a water level 10 cm below the surface. The Alberta results do not corroborate findings from another rewetted peatland of which Meade (1992) documented higher concentrations of NO_3 and lower concentrations of NH_4 in wetter areas compared to drier areas.

Sulfur increases in concentration with depth in the peat profile, possibly due to changes in solubility and/or increasing humification and decomposition of the other peat elements (Zoltai and Johnson 1987). Similar concentrations of sulfur were recorded in the surface peat of the harvested and natural areas of the Alberta site. With the drier conditions on the harvested site, reduced sulfur compounds may have been reoxidized in the peat and transferred to the water (Bayley et al. 1986).

2.6 Conclusions and implications for restoration

The removal of surface bog peat for peat harvesting activities has altered the peat and water chemistry of the four post-harvested peatlands, moving them back in the fen to bog succession time sequence. All the harvested sites had raised nutrient conditions of nitrate and ammonia, and all had more variation in elemental concentrations when compared to the natural areas. Natural, undisturbed bogs have fairly narrow ranges of elemental concentrations in water and peat. Harvested peatlands have more variation due to more varied conditions, including the extent to which fen peat is exposed, differing moisture levels, and amount of vegetation cover.

Although the central Québec harvested site still has bog chemical conditions, the New Brunswick and eastern Québec harvested sites are now more similar to poor fens, while the Alberta harvested site is similar to a moderate-rich fen. The exposed fen peat resulted in higher concentrations Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and Cl^- in the water. Higher concentrations of nitrate-nitrogen and ammonium-nitrogen in the water and the peat of the post-harvested sites may be explained by a variety of possible factors. Increased aeration and higher pH values may have allowed more aerobic and nitrifying bacteria to grow, and more organic nitrogen to be mineralized. The lack of vegetation may have allowed the high nitrogen concentrations to remain intact.

The information obtained from this research characterizes post-harvested peatland conditions. This characterization identifies the differences between natural and harvested peatlands in order to further understand peatland processes and develop restoration measures for these and other post-harvested sites. In particular, relating high nutrient values, increased element contents, and large variation in chemistry indicate that harvested surfaces differ considerably from the original, natural surface.

Since most peatland plants have narrow tolerances to chemical conditions, and are largely limited in their distribution by chemical properties (Sjörs 1950, Sjörs 1952, Gignac et al. 1991a), chemical characterization of harvested peatlands is critical for restoration procedures. Selection of appropriate species for restoration must take these factors into consideration. This research should be used in conjunction with predictive models (such as the response surface model, Gignac et al. 1991a, Gignac et al. 1991b) which predict appropriate peatland bryophyte species for given variables of water pH, height above water level, and climate.

Chemistry analyses also indicate the limitations of restoration of a particular post-harvested peatland. Bogs that have been harvested to moderate-rich fen surface layers are not likely to be appropriate for ombrotrophic bog plants. Fen species are a better choice for restoration, with emphasis on transitional *Sphagnum* species to help acidify the system. For example, although the chemical conditions are more similar to those of a moderate-rich fen at the Alberta site, *Sphagnum angustifolium* regenerates well if the moisture levels are sufficient, and may help to acidify the site.

Although it has been shown that *Sphagnum* in natural peatlands has increased growth rates with nitrogen additions in some locations (Rochefort et al. 1990, Aerts et al. 1992), post-harvested peatlands have concentrations much higher than undisturbed peatlands; thus nitrogen fertilizer additions are not necessary for the restoration of these sites.

Finally, this study indicates that initial site characterization as well as periodic monitoring of site chemistry is necessary in order to provide sufficient data for successful restoration of harvested peatland sites.

Table 2-1.
Means (and ranges) of water chemistry data of the natural areas of the four sites

	New Brunswick 1992/1993	eastern Québec 1993	central Québec 1993	Alberta 1993
n	8	1	3	2
pH	3.9 (3.8-4.0)	3.7	3.7 [b] (3.6-3.8)	3.7 (3.7)
Corrected Conductivity ($\mu S/cm$)	30 (0-70)	97	58 [a] (0-115)	0 (0)
P total (mg/L)	<0.1 (<0.0-<0.1)	0.0	0.0 (0.0-0.2)	0.1 (0.0-0.1)
NH_4^+-N (mg/L)	1.6 (0.4-2.8)	<0.1	0.2 [b] (0-1.4)	0.1 (0.1-0.1)
NO_3^--N (mg/L)	<0.1 (<0.1-<0.1)	0.06	<0.1 [b] (0-<0.1)	0.0 (0.0-0.0)
Na^+ (mg/L)	4.1 (2.2-8.0)	16.5	0.3 (0.1-0.5)	1.0 (0.9-1.1)
K^+ (mg/L)	0.3 (0.2-0.4)	<0.4	0.2 (0.2-0.3)	0.2 (0.2-0.3)
Ca^{2+} (mg/L)	0.4 (0.2-0.6)	4.6	0.6 (0.5-0.8)	3 (2.8-3.2)
Mg^{2+} (mg/L)	0.5 (0.3-0.6)	3.1	0.3 (0.2-0.3)	1.1 (1.1-1.1)
SO_4^{2-} (mg/L)	1.9 (1.1-2.9)	9.6	2.6 [a] (0.7-3.5)	2.4 (1.9-2.9)
Cl^- (mg/L)	5.0 (3.1-9.8)	3.4	0.1 [a] (0.1-0.2)	0.5 (0.4-0.5)

Notes: [a] n=2. [b] n=5 .

Table 2-2.
Means (and ranges) of peat chemistry data of the natural areas of the four sites

	eastern Québec 1993	central Québec 1992/1993	Alberta 1992/1993
n	1	1	2
pH	2.71	2.85	4.15 [a]
Corrected Conductivity (µS/cm)	0	0	10 [a]
P total (mg/kg)			406.3 (387.7-424.9)
NH_4-N (mg/kg)		690	112.0 (80.2-143.8)
NO_3-N (mg/kg)			1.4 (0-2.7)
Na (mg/kg)	260	400	110.2 (106.1-114.2)
K (mg/kg)	800	830	241.6 (114.8-368.3)
Ca (mg/kg)	1500.0	1100.0	6236.0 (5615-6856)
Mg (mg/kg)	830.0	390.0	855.7 (705.3-1006)
S (mg/kg)			1529 (974.3-2083)

Notes: [a] n=1.

Table 2-3.
Means (and ranges) of water chemistry data of the harvested areas of the four sites

	New Brunswick 1992/1993	eastern Québec 1993	central Québec 1992/1993	Alberta 1991/1992/1993
n	38	3	25	20
pH	3.7 (3.4-4.0)	5.3 (5.2-5.4)	4.0 [a] (3.7-4.4)	5.6 [f] (4.8-8.7)
Corrected Conductivity (μS/cm)	82 (32-164)	110 (90-143)	33 [b] (0-119)	57 [g] (20-253)
P total (mg/L)	<0.1 (<0.0-0.4)	0.0 (<0.6-<0.6)	0.1 (0.0-0.2)	0.4 (0.1-1.1)
NH_4^+-N (mg/L)	5.4 (1.8-15.8)	1.6 (1.6-1.6)	2.0 [c] (0.0-5.7)	3.6 (0.1-9.4)
NO_3^--N (mg/L)	0.1 (<0.1-0.9)	0.3 (0.0-0.6)	0.1 [d] (<0.1-0.2)	0.2 (0.0-2.7)
Na^+ (mg/L)	7.2 (3.2-21.9)	11.0 (9.4-12.3)	0.5 (0.2-1.0)	6.1 (1.8-13.9)
K^+ (mg/L)	0.9 (0.3-4.2)	2.2 (2.1-2.5)	0.4 (0.1-0.8)	2.6 (1.5-3.8)
Ca^{2+} (mg/L)	0.3 (<0.1-1.4)	5.3 (1.2-8.3)	0.9 (0.2-2.3)	12.6 (2.3-28.7)
Mg^{2+} (mg/L)	1.3 (0.4-4.9)	2.8 (0.8-4.4)	0.3 (0.0-1.8)	4.1 (0.8-11.9)
SO_4^{2-} (mg/L)	12.1 (6.1-25.1)	9.7 (1.2-17.4)	2.7 [b] (<0.1-7.6)	8.6 [h] (1.3-26.7)
Cl^- (mg/L)	13.5 (6.9-26.2)	4.6 (1.2-7.2)	0.6 [e] (0.1-1.5)	1.0 [h] (0.6-1.6)

Notes: [a] n=37. [b] n=31. [c] n=29. [d] n=36. [e] n=16. [f] n=54. [g] n=29. [h] n=13.

Table 2-4.
Means (and ranges) of peat chemistry data of the harvested areas of the four sites

	New Brunswick 1993	eastern Québec 1993	central Québec 1992/1993	Alberta 1991/1992/1993
n	6	4	16	62
pH	3.6 (3.4-3.9)	3.5 (3.2-4.0)	2.9 [a] (2.8-3.0)	4.4 [d] (3.8-8.0)
Corrected Conductivity (µS/cm)		0 (0)	103 [b] (0-256)	66 [d] (0-600.4)
P total (mg/kg)				362.7 (176.2-624.0)
NH_4-N (mg/kg)	640 (500-900)		1533 [a] (930-1900)	121.1 [e] (13.5-711.6)
NO_3-N (mg/kg)				78.1 [e] (0-433.0)
Na (mg/kg)		180 (170-210)	112 (19-250)	466.1 (51.2-9393)
K (mg/kg)		160 (150-190)	138 (36-260)	297.2 (56.7-3096)
Ca (mg/kg)		3000 (290-7000)	1007 (700-1833)	7433 (2261-16220)
Mg (mg/kg)		2280 (1800-3400)	197 (136-253)	1135 (407-3269)
S (mg/kg)			1500 [c] (1200-2000)	1820 (570-11740)

Notes: [a] n=7. [b] n=34. [c] n=9. [d] n=139. [e] n=88.

Table 2-5.
Surface water nitrogen content from undisturbed peatlands in Canada

Peatland type	Region B=boreal, C=continental, M=maritime	Mean NO_3^--N (mg/L)	Mean NH_4^+-N (mg/L)	Reference
Bog	B - Alberta	0.002	0.020	Nicholson 1987
	B - Alberta	0.009	0.018	Vitt et al. 1995
	B - Alberta	0.002	0.023	Thormann 1995
	C - Québec and New Brunswick	0.018	0.179	Rochefort, unpublished
	M - Québec and New Brunswick	0.002	0.124	Rochefort, unpublished
Poor fen	B - Alberta	0.001	0.013	Vitt and Chee 1990
	B - Alberta	0.007	0.014	Vitt et al. 1995
	C - Québec and New Brunswick	0.002	0.124	Rochefort, unpublished
	M - Québec and New Brunswick	0.001	0.001	Rochefort, unpublished
	northwest Ontario	<0.001		Bayley et al. 1987
Moderate-rich fen	B - Alberta	0.001	0.054	Vitt and Chee 1990
Moderate-rich fen (open)	B - Alberta	0.001	0.028	Thormann 1995
Moderate-rich fen (open)	B - Alberta	0.006	0.010	Vitt et al. 1995
Moderate-rich fen (forested)	B - Alberta	0.006	0.015	Vitt et al. 1995
Extreme-rich fen	B - Alberta	0.002	0.010	Vitt and Chee 1990
	B - Alberta	0.001	0.025	Thormann 1995
	B - Alberta	0.015	0.022	Rochefort, unpublished
	B - Alberta	0.006	0.007	Vitt et al. 1995
	C - Québec and New Brunswick	0.001	0.001	Rochefort, unpublished

Table 2-6.
Surface peat nitrogen content from undisturbed peatlands in boreal Alberta, Canada (Harkonen 1985)

Peatland type	Mean NO3-N (mg/kg)	Mean NH4-N (mg/kg)
Bog	0.9	53.7
Poor fen	1.4	64.6
Moderate-rich fen	1.4	108.1
Extreme-rich fen	1.1	68.4

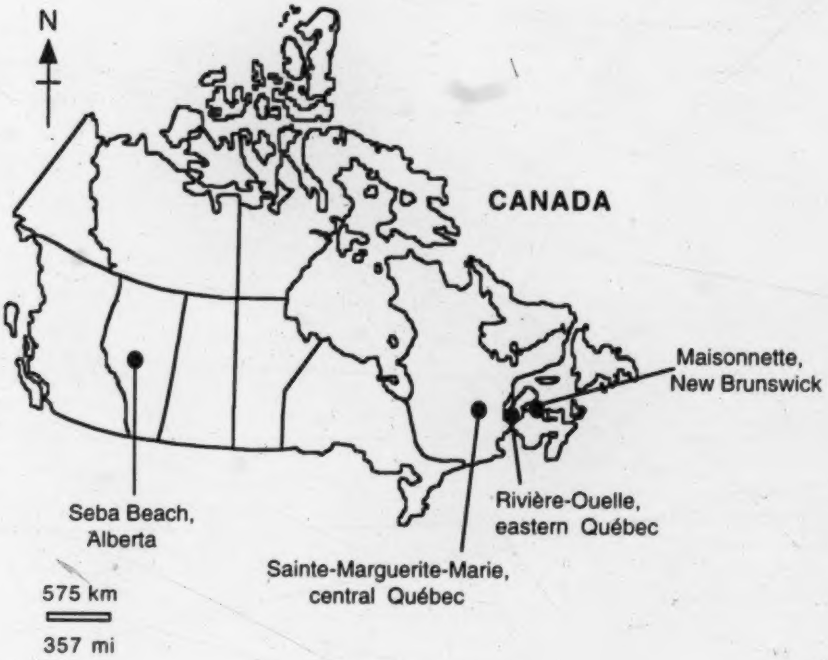
N
CANADA
Maisonnette,
New Brunswick
Seba Beach,
Alberta
Rivière-Ouelle,
eastern Québec
Sainte-Marguerite-Marie,
central Québec
575 km
357 mi

Figure 2-1. Locations of the study sites across Canada.

One site in Alberta, Seba Beach. Two sites in Québec, Sainte-Marguerite-Marie and Rivière-Ouelle. One site in New Brunswick, Maisonnette.

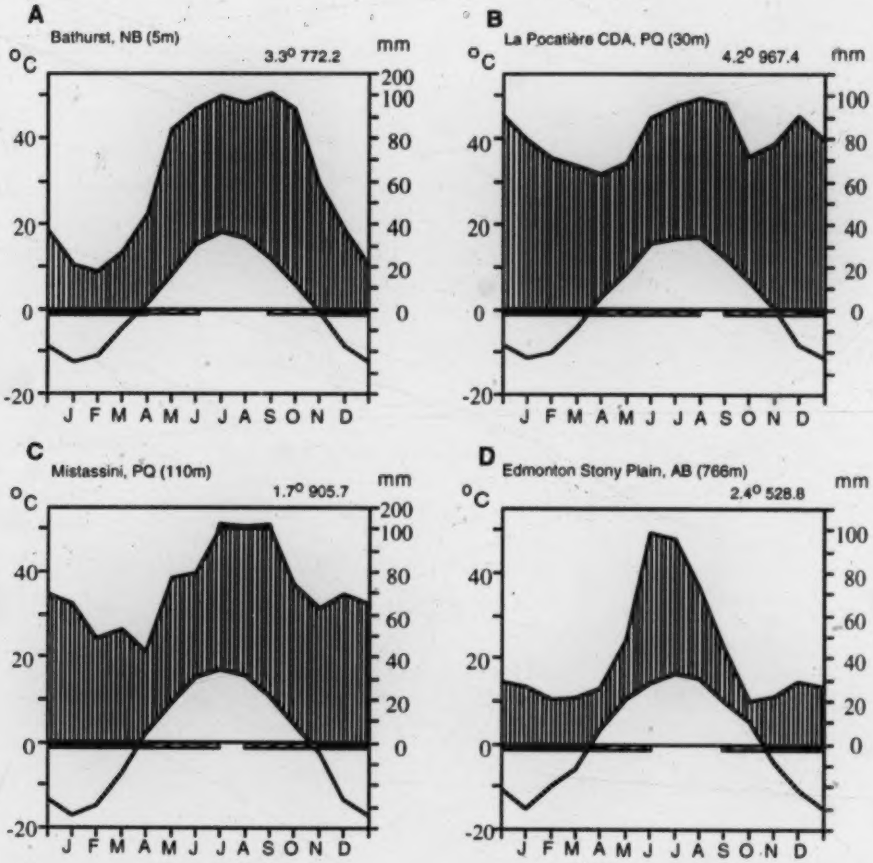

Figure 2-2. Climate diagrams of the study sites, after Walter and Leith (1960).

A/ New Brunswick: Maisonnette peatland area. Mean annual temperature, 3.3°C; mean annual precipitation, 772.2 mm; height above sea level, 5 m.

B/ Eastern Québec: Rivière-Ouelle peatland area. Mean annual temperature, 4.2°C; mean annual precipitation, 967.4 mm; height above sea level, 30 m.

C/ Central Québec: Sainte-Marguerite-Marie peatland area. Mean annual temperature, 1.7°C; mean annual precipitation, 905.7 mm; height above sea level, 110 m.

D/ Alberta: Seba Beach peatland area. Mean annual temperature, 2.4°C; mean annual precipitation, 528.8 mm; height above sea level, 766 m.

For all the graphs: the upper line is precipitation, the lower line is temperature, the solid bar is months with mean monthly temperature <0°C, the diagonally hatched bar is months with absolute minimum temperature <0°C.

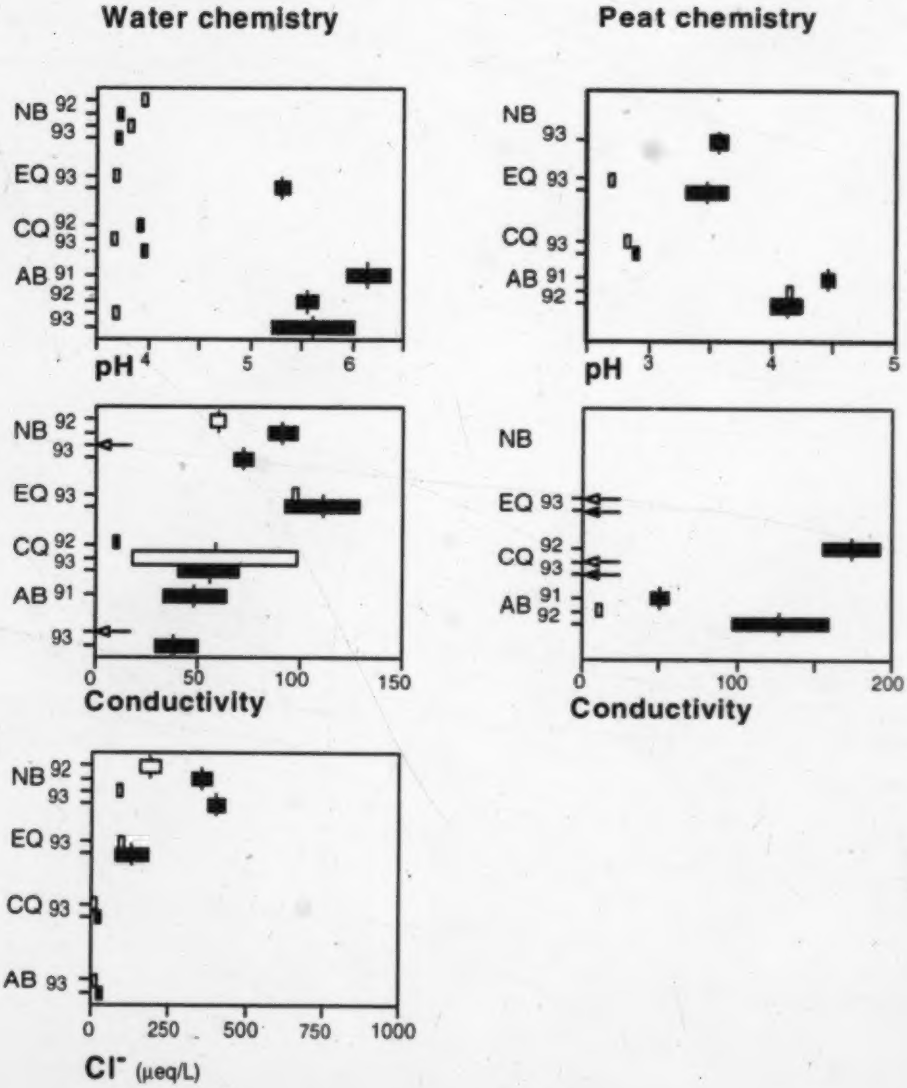

Figure 2-3a. Annual means ± standard errors of water and peat chemistry of harvested and undisturbed peatlands for pH, corrected conductivity (µS at 20°C, corrected for pH) and Cl-.

NB=New Brunswick. EQ=Eastern Québec. CQ=Central Québec. AB=Alberta. The white bar represents undisturbed peatland values, the solid bar represents post-harvested peatland values. Arrows indicate values below 35.7. Narrow bars ▮▯ indicate standard errors below 25 for water values and 39 for peat values.

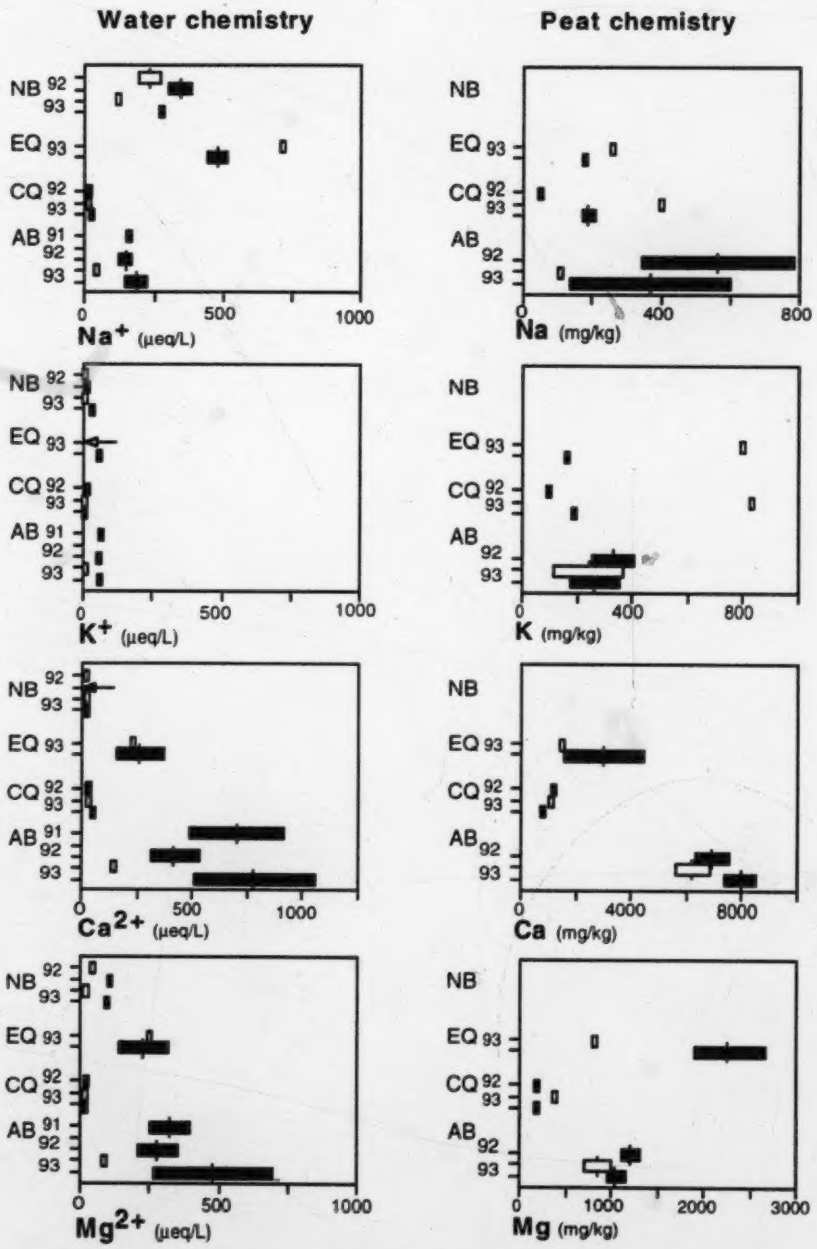

Figure 2-3b. Annual means ± standard errors of water and peat chemistry of harvested and natural peatlands for cations (Na, K, Ca, and Mg). Legend the same as in Figure 2-3a.

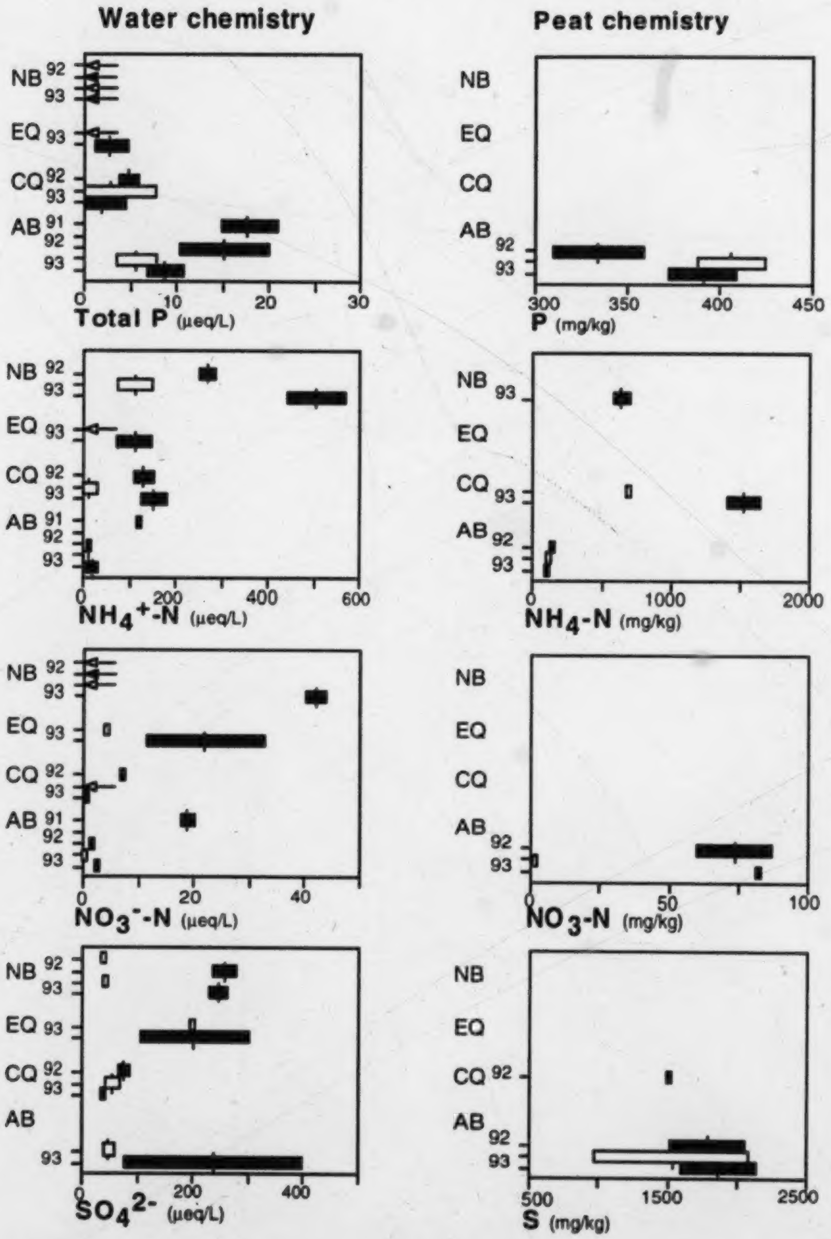

Figure 2-3c. Annual means ± standard errors of water and peat chemistry of harvested and natural peatlands for nutrients (total P, P, NH_4-N, NO_3-N, SO_4 and S).

Legend the same as in Figure 2-3a.

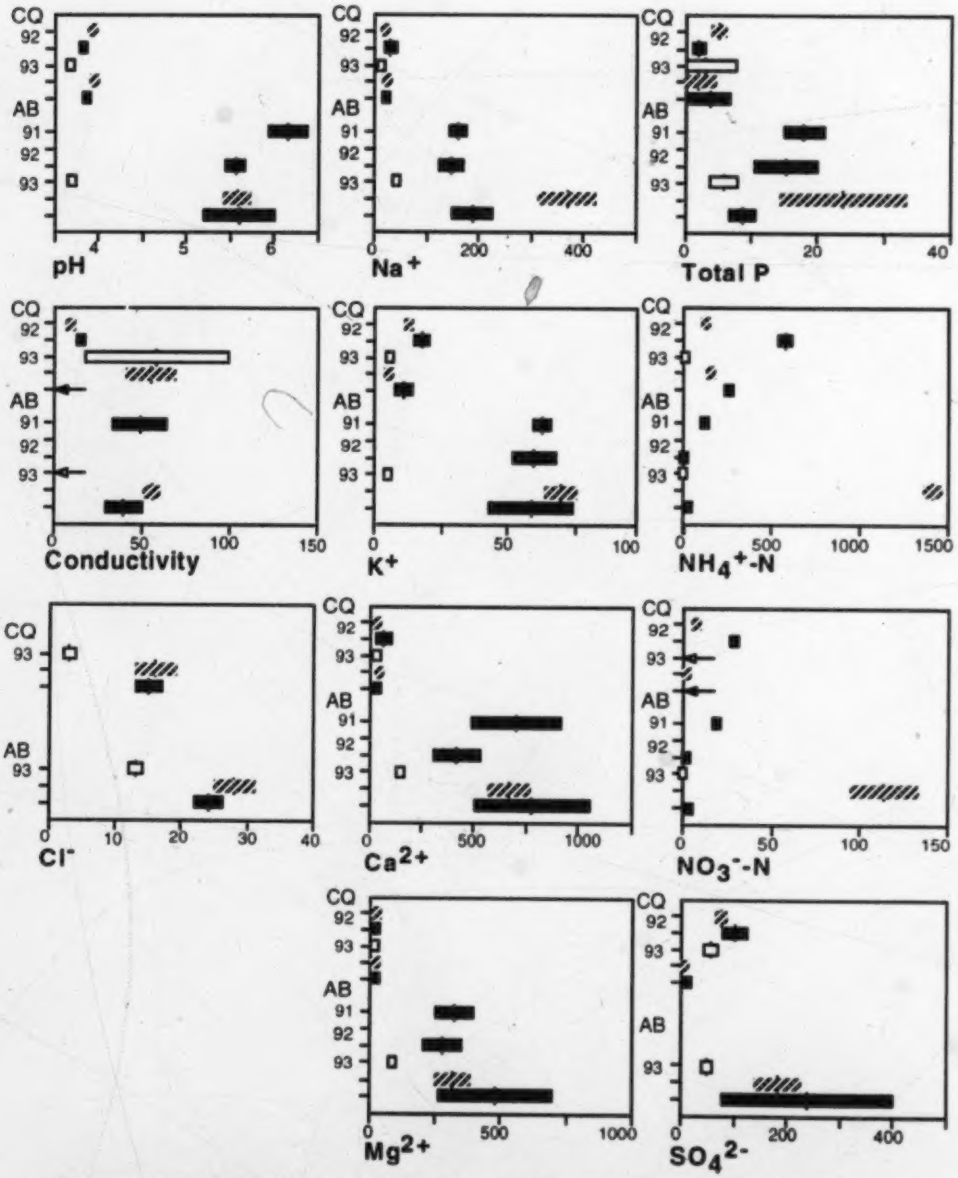

Figure 2-4. Annual water chemistry means (± SE) from Sainte-Marguerite-Marie, central Quebec (CQ) and Seba Beach, Alberta (AB).

Corrected conductivity (µS at 20°C, corrected for pH). The white bar represents the undisturbed peatland values; the hatched bar represents the harvested area, surface pit or water level pipe; the solid bar represents the harvested area ditch. All units are µeq/L except pH and conductivity (µS at 20°C, corrected for pH). Arrows represent values below 3.6.
Narrow bars, □▨■ , indicate standard errors below 26.7.

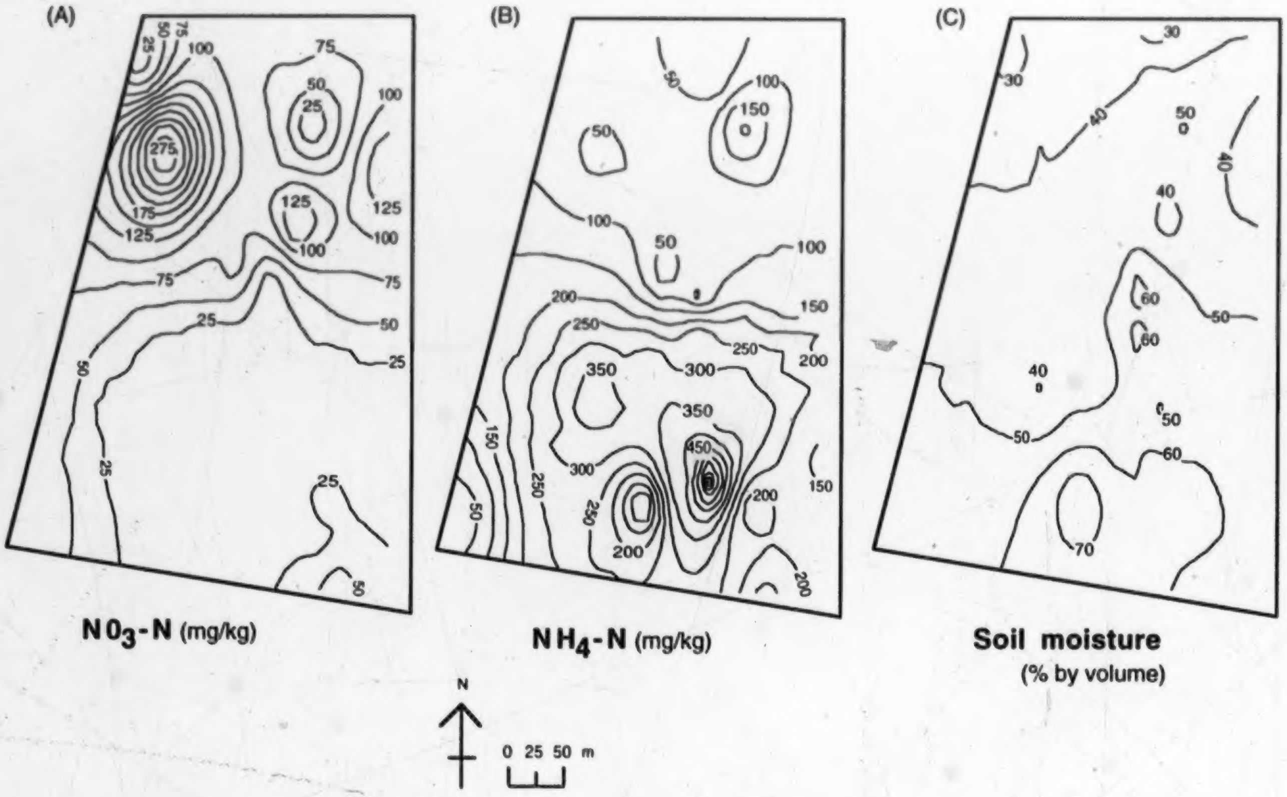
(A)
(B)
(C)
NO3-N (mg/kg)
NH4-N (mg/kg)
Soil moisture
(% by volume)
N
0 25 50 m
25
50
75
100
125
175
275
150
200
250
300
350
450
30
40
60
70

Figure 2-5. (A) Available nitrate-nitrogen, (B) available ammonia-nitrogen across the Seba Beach harvested site (in mg/kg). (C) Soil moisture (% by volume) across the site. 1992 values.

2.7 References

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Chapter 3.

Comparisons of water and peat chemistries of a post-harvested and undisturbed peatland with relevance to restoration

3.1 Introduction

Peatlands are an interesting and important ecosystem in Canada, where they cover 170 million ha, more than in any other country (Gorham 1990). A very small portion of this area is harvested for horticultural peat moss. Vacuum harvesting is the most common harvesting method in Canada. With this method, drains are installed in large areas, surface peatland vegetation is removed, and the fibric, high *Sphagnum* content peat is slowly harvested over years to decades. When layers of subquality peat are reached in the peat deposit, harvesting is stopped. Restoration measures are necessary to return the site to a functioning peatland, as abandoned, harvested sites do not appear to revegetate quickly (see Chapter 1).

One necessary step in the restoration process is to assess the chemical state of the post-harvested peatland. By comparing with undisturbed peatlands, changes in elemental concentrations, nutrient status, and successional peatland type can be determined. As site chemistry influences type and growth of peatland vegetation, this information is necessary to develop a site-specific restoration plan.

In the previous chapter, spatial variability of water and peat chemistry characteristics of four post-harvested and associated natural peatlands across Canada was examined. In this chapter, temporal variability of one post-harvested and one neighbouring natural peatland in Seba Beach, Alberta is the focus. Data from five years of research are analyzed. The objectives of this chapter are to determine chemical differences between the harvested site and natural peatland, and to determine the extent of chemical change that results from peat removal.

3.2 Site description

The Seba Beach peatland is located about 130 km west of Edmonton (53°33'N, 114°44'W). This peatland is classified as a Continental Mid-Boreal peatland (NWWG 1986), typical of ombrotrophic bogs in the southern boreal forest of continental western Canada. The area has a mean annual temperature of 2.4 °C, with a mean January temperature of -15 °C and mean July temperature of 16 °C. Average annual precipitation for the area is 528.8 mm, with a quarter of the total precipitation falling as snow (Environment Canada 1982a, 1982b).

Originally this peatland was covered by bog and poor fen vegetation dominated by *Picea mariana, Sphagnum fuscum, S. magellanicum, S. angustifolium*, and a few scattered *Larix laricina*. This site was first opened in 1975 to harvesting by dredging. In 1980, Fisons Horticulture Inc., now Sun Gro Horticulture Canada Ltd., acquired the site and leveled, drained, and then vacuum harvested the area. The restoration site is approximately 16 hectares in area, 0.02% of the area presently being harvested by Sun Gro. The peat surface is highest in the northeastern corner, sloping downward to the southwest corner, with drainage southwestward. Drainage ditches run east/west, dividing the field into 20 harvesting bays. The perimeter ditch runs along the western edge. Peat depth ranges from 0.73 m at the northern end, deepening at the southern end to over 4 m.

To raise the water level, a dam was constructed in the southwestern corner in the fall of 1991, following the cessation of peat harvesting. Over the years 1992-1995 water levels increased, although conditions were quite varied across the field, ranging from dry to flooded (see chapter 4).

The natural peatland is located along the western edge of the harvested site. The vegetation is mainly composed of *Picea mariana*, *Ledum groenlandicum*, *Andromeda polifolia*, and *Sphagnum* mosses such as *Sphagnum fuscum*, *S. magellanicum*, and *S. angustifolium*. A site description of a section of the natural area is outlined in Li and Vitt (1997).

3.3 Methods

3.3.1 Water chemistry

Surface water samples were obtained from pools, ditches, or from within water level wells. On the harvested site, ditches were first sampled, randomly, but approximately equally along the western quarter. With the installation of water level wells, additional water samples were obtained from the surface water within the well, either by immersing the sample bottle in the well, or by drawing water up by suction with a syringe and rubber hose. In the natural area, water samples were obtained within the well, and from nearby shallow pools. Water samples were collected in July and August 1991, June and August 1992, August 1993, September 1994, and July 1995. Sample size for ditch water samples ranged from 2-15 from 1991-1995 (Table 3-1 indicates yearly n sizes). In the years 1993-1995, 10 yearly water samples were collected from the wells in the harvested area, and 2 yearly water samples were collected in the natural.

Surface water pH was measured digitally in the field or in the lab (Stainton et al. 1977 methods). Surface water samples were measured for conductivity values with corrections for temperature at 20 °C and hydrogen ions (Sjörs, 1952). Surface water nutrients were analyzed by the Department of Zoology at the University of Alberta. Water samples were stored in 1-L Nalgene polyethylene bottles for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total phosphorus (TP), and NO_3^--N analyses. Water samples for NH_4^+-N analyses were stored in 250 ml polystyrene flasks. Samples for Na^+, K^+, Ca^{2+}, and Mg^{2+} were filtered through a prewashed Whatman GF/C filter, stored at 4 °C, and analyzed on an atomic absorption spectrometer (Perken-Elmer, model 3300). Analyses of Cl^- and SO_4^{2-} were conducted by ion chromatography with a Waters chromatographic system. Samples for TP were filtered under low pressure (-50 kPa), through a 250-μm Nitex net and transferred to culture tubes (Prepas and Rigler 1982; modified from Menzel and Corwin 1965). These samples were analyzed colormetrically on a Milton Roy Spectronic Spectrometer. After filtration through a prewashed 0.45-μm HAWP Millipore membrane filter, nitrate was determined on the technicon by the cadmium-copper reduction method of Stainton, Capel and Armstrong (1977). Ammonium samples were analyzed on the technicon by Solorzano's (1969) phenolhypochlorite method as modified by Prepas and Trew (1983).

3.3.2 Peat chemistry

Peat samples were collected from 0-5 cm profiles from the harvested peat surfaces and from 1-5 cm profiles in the natural area, using a TJ-10.5 corer, a tomato juice can with one edge cut to form a handle, and the other cut and filed to form a sharp cutting edge, with an opening diameter of 10.5 cm. In the natural area, random samples were gathered within the vicinity of the natural area well (n=2, with the occasional exception, see Table 3-2). In the harvested area, peat sampling varied between years. In July 1991, the harvested field was sampled for peat pH and conductivity by dividing the field into 70 m sections along the bays, and randomly collecting samples within each section (n=86). In July and August 1992, the sampling design was altered to reduce the sample size for financial considerations. Each harvesting bay was divided in half, and was randomly sampled within each section (n=40). Peat samples were either fully or partially analyzed (Table 3-2 indicates the size n for each chemical component). In 1993-1995, peat samples collected along the western quarter were randomly placed near to selected revegetation plots, while the rest of the site was divided into 4-8 sections and randomly sampled within each section. In September 1993, 40 peat samples were collected, and in September 1994 and July 1995, 20 peat samples were analyzed. Samples were stored in polyethylene bags at a cool temperature until analysis.

Peat pH was analyzed using a 1:2 ratio of fresh peat and distilled water using methods from the Department of Soil Science at the University of Alberta (1990). Peat conductivity analyses were conducted using the same ratios. Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs (1952). Peat pH and conductivity samples were measured by the author with the aid of various assistants. Bulk density was analyzed by oven drying peat samples of known volumes at 60 °C.

Surface peat samples were analyzed for the elements Ca, K, Mg, Na, P, and S by dry ashing methods. Peat samples were ovendried at 60 °C, and then ground to 1/2 mm or less. Subsamples 0.3-0.4 g were dry ashed at 470 °C, and acid digested with 6 ml 1.5 N HCl and 1 ml concentrated HNO_3. Digested samples were filtered through Whatman #42 filter paper and analyzed by inductively coupled plasma spectrophotometry. Available nitrate and ammonia were extracted by using 1:20 ratio of air-dry ground peat and 2N KCl, mechanically shaken for 30 minutes and analyzing the filtrate using a technicon autoanalyser and the Industrial Methods 158-71 W/B, December 1972, and 696-82W, April 1983, respectively. Samples were prepared by the author with the aid of various assistants, and analyzed by the Department of Zoology at the University of Alberta (available NO_3-N, and available NH_4-N samples) and by Forestry Canada, Northern Forestry Centre (Ca, K, Mg, Na, P, and S samples).

3.3.3 Statistical analyses

Yearly chemistry data were grouped according to sampling sources. Peat chemistry data were either from the harvested field or the neighbouring natural area. Water chemistry data were grouped into three source categories: natural area, harvested site ditches, and harvested site wells. The chemistry data were not normally distributed and variances were not homogenous. Spread versus level graphs and power of transformation values were generated, and transformations to normalize the data were attempted. Transformations could not fully normalize the data and homogenize the variances. Thus, nonparametric tests were used, with an alpha value consistently set at 0.05. For the water chemistry analyses Kruskal-Wallis 1 Way analysis of variance tests determined differences between years within sampling sources. Distributions of significant differences were resolved by Tukey Type Multiple Comparisons tests. Since there were few significance differences between years within the sampling source categories, the yearly results were combined and differences between source categories were analyzed by Kruskal-Wallis 1 Way analysis of variance tests, followed by Tukey Type Multiple Comparisons tests.

For the peat chemistry analyses, testing was similar except that many chemical elements had significant differences between years. Therefore, Mann-Whitney U-Wilcoxon Rank Sum W tests were used to determine differences within years between the natural and harvested area. The computer package SPSS was used for all these statistical tests (SPSS 1995), with the exception of the Tukey Type Multiple Comparisons tests which were calculated by the author.

In addition to these statistical tests, the yearly variation of each sampling source was calculated as a coefficient of variation for each chemical component, for both water and peat chemistry. These yearly coefficients of variation were averaged for each component, then components of similar unit based measurements were ranked in order of increasing variation and compared. These calculations make it possible to compare relative variability of the chemical factors for each sampling source, as both mean and standard deviation (dispersion) are taken into account.

3.4 Results

3.4.1 Natural area - Water chemistry

Generally, the water chemistry of the natural area had lower concentrations and less variation than did the harvested site (Table 3-1). Mean annual pH in the surface water of the natural area was consistently 3.7, while mean annual conductivity ranged from 0-28 μS/cm (Figure 3-1, white bars). Cation concentrations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) were lower than those of the harvested site (Figure 3-1, white bars). Listed in decreasing order of concentration, total phosphorus, NH_4^+-N and NO_3^--N in the natural area had mean annual ranges of 5.7-7.8 μeq/L, 3.2-5.5 μeq/L, and 0.4-0.8 μeq/L, respectively (Figure 3-1, white bars). The natural area had consistent chemical concentrations over the years, with no significant differences between years. Mean coefficients of variability in the natural area were ranked according to increasing variability in the following order: $Ca^{2+} < Mg^{2+} < Na^+ < NO_3^-\text{-N} < Cl^- < SO_4^{2-} < K^+ < NH_4^+\text{-N} < TP$ (Figure 3-2). The natural area had hydrochemical values similar to other bogs of continental western Canada recorded in the literature (Nicholson 1993; Vitt et al. 1995).

3.4.2 Natural area - Peat chemistry

Peat chemistry values in the undisturbed area tended to be lower than in the harvested site (Table 3-2), and similar to other natural bogs (overview in Nicholson 1993). Mean annual peat pH ranged from 4.1-4.3 and mean annual conductivity ranged from 5-10 μS/cm (Figure 3-3, white bars). The elements Ca, Mg, Na and S all had concentrations lower in the natural area (Figure 3-3, white bars). Phosphorus and potassium were the only chemical elements that had higher means in the natural area than in the harvested field (Table 3-2). Phosphorus had a mean annual range of 406-653 mg/kg. The available nutrients NH_4-N and NO_3-N had mean annual ranges of 51.8-112.0 mg/kg and 0.1-1.4 mg/kg (Figure 3-3, white bars). No significant differences between years were present for peat chemistry within the natural area. Mean coefficients of variability for the natural area peat chemistry increased in variability in the following order:

$Na < P < Ca < Mg < S < K < NH_4\text{-}N < NO_3\text{-}N$ (Figure 3-4).

3.4.3 Harvested area - Water chemistry

Generally, the surface water chemistry from both the ditches and from within the wells had higher concentrations than the natural site. In the wells, mean annual surface water pH ranged from 4.9-5.6 and mean annual conductivity ranged from 56-106 µS/cm, while the ditch samples had a slightly higher pH and slightly lower conductivity range of 5.2-6.2 and 40-90 µS/cm, respectively. The ditches had lower or similar annual means as the well category for the cations Na^+, K^+, Ca^{2+}, and Mg^{2+}. Generally, the water from within the wells had higher nutrient values for total phosphorus, NH_4^+-N and NO_3^--N than from the ditches (Figure 3-1, striped and solid black bars). Values for SO_4^{2-} and Cl^- overlapped for the well and ditch sources, and the annual means for both harvested groups were higher than those values of the undisturbed site.

The sequence of increasing variability for mean coefficients of variability for the well and ditch water sources differed from the natural area and from each other (Figure 3-2). Variability increased in the well samples in the following order:

$K^+ < Mg^{2+} < Cl^- < Ca^{2+} < Na^+ < TP < SO_4^{2-} < NH_4^+\text{-}N < NO_3^-\text{-}N$,

while ditch samples had this order:

$Cl^- < K^+ < Na^+ < NO_3^-$-N $< Mg^{2+} <$ TP $< Ca^{2+} < NH_4^+$-N $< SO_4^{2-}$. Within each sequence, the coefficient numbers tended to be close in value, with the top two or three components being higher in variation.

Testing of differences between years within the sampling sources showed only a few significant differences within the various water chemistry components (Table 3-3). The pH of the ditch samples in 1994 was significantly lower than the 1991 values, and corrected conductivity was higher in 1992 and 1994 compared to 1991 values, but otherwise the years were not significantly different. The well samples had differences between years for NH_4^+-N and Cl^-. In 1993, the NH_4^+-N values were significantly higher than the subsequent years, and in 1994 Cl^- values were significantly higher than the other sampled years.

With the yearly data grouped together, sampling source comparisons showed significant differences in all the water chemistry attributes except SO_4^{2-} (Table 3-3). The properties pH, Na^+, and K^+ had all three sampling sources significantly different from each other. The wells and ditches were both significantly higher than the natural site for corrected conductivity, and the cations Ca^{2+}, Mg^{2+} and NO_3^--N. For total P, the well category was significantly higher than both the ditch and the natural area sources. For NH_4^+-N and Cl^-, the well source was only significantly higher than the natural area category.

3.4.4 Harvested area - Peat chemistry

Some trends observed in the water chemistry of the harvested site were also seen in the peat chemistry. With the exception of P and K, peat chemistry values for the harvested site were usually higher than the natural area values (Table 3-2). In the harvested site, mean annual peat pH varied from 4.1-4.6, and peat conductivity ranged from 37-131 µS/cm (Figure 3-3, solid bars). Mean annual phosphorus concentrations ranged from 335-405 mg/kg. Available NH_4-N and NO_3-N ranged from 104-138 mg/kg and 17-83 mg/kg for the annual means, respectively. The order of increasing variability, as measured by coefficients of variability, was similar to the natural area peat chemistry, with the exception that Na was not the chemical component with the lowest coefficient of variability, but rather the highest (Figure 3-4).

Testing of differences between years within the harvested area showed a number of significant differences within the peat chemistry components (Table 3-4). In 1991, corrected conductivity was significantly lower than in the following years. In 1992, pH was significantly lower, in 1993 Na and water content in the peat were both significantly lower, and in 1995 available NO_3-N was significantly lower than in the other years. No consistent trends were discerned in these results, except that there were more observed yearly differences in the peat chemistry results than in the water chemistry results.

Some significant differences between the natural area and harvested area within years were noted in the peat chemistry data (Table 3-4). In 1993, significant differences in available NO_3-N and bulk density were found. In 1994, significant differences were observed in pH, corrected conductivity, Mg, P, S, and bulk density. In 1995 corrected conductivity, water content and bulk density had significant differences between the natural and harvested sites. The only two chemical components which did not show some significant differences between the harvested and natural sites within years were Na, and available NH_4-N.

3.5 Discussion

3.5.1 Water chemistry

Removal of the upper peat layers with harvesting has affected the water chemistry of this post-harvested site. Although the low number of sample values for the natural area may have reduced the power of some of the statistical tests, the data obtained from the natural area are similar to other bogs in continental western Canada reported in the literature (Zoltai and Johnson 1987; Nicholson 1993; Vitt et al. 1995). The low chemical concentrations found in the natural area are in contrast to the higher concentrations in the post-harvested site, which show the effects of exposure to more minerotrophic peat in the harvested area. All the chemical components from the harvested area well samples were significantly higher than from the natural area. The water chemistry is no longer typical of a bog, but now is similar to a poor or moderate-rich fen (Vitt and Chee 1990).

Water samples from both the ditches and the wells in the middle of harvested bays had similarly high chemical concentrations. However, chemical concentrations were higher in the wells than in the ditches, and this was possibly due to differences in vegetation growth around the two water sources. Vegetation grew on the ditch banks throughout the study, while vegetation cover around the wells was low, although it did increase over the years. The good vegetation growth in the ditches may have resulted in a higher level of aqueous nutrients being consumed. Two chemical components, pH and K^+, were significantly higher in the ditches compared to the well samples. Possibly the exposure of deeper peat in the ditches resulted in higher concentrations for these two components. Thus, chemical conditions in the ditches and on the harvested bays are different.

Nutrient concentrations of total P, NH_4^+-N and NO_3^--N were significantly higher in the harvested site than in the natural area, and were higher than values recorded from other undisturbed peatlands (chapter 2, Table 2-3). Total P concentrations were significantly higher in the wells than in the ditches or natural area, possibly due to the lower vegetation cover on the harvested bays. Several reasons could explain why the aqueous NH_4^+-N and NO_3^--N values were higher in the post-harvested site than in the natural area. The harvested area had higher pH values which may allow more nitrifying bacteria to grow (Dickinson 1983). Some portions of the harvested site were quite dry which may have favored more biological activity of aerobic microbes (Lähde 1969), and higher numbers of nitrifying bacteria (Waksman and Stevens 1928; Zimenko and Misnik 1970; Dunican and Rosswall 1974). These micro-organisms mineralize more organic nitrogen (Heikkinen 1990). Overall low vegetation growth on the harvested site may have permitted higher nitrogen concentrations to remain available, due to lack of nitrogen consumption.

While nutrient concentrations were always higher in the harvested site than the natural peatland, concentrations of NH_4^+-N did significantly decrease in the wells in 1994 and 1995 (Table 3-3). As mentioned above, vegetation cover was low on the harvested bays, yet vegetation cover did increase over the years, especially in the wetter areas. Randomly placed permanent control plots showed a mean annual vegetation cover increase of 0 to 10% in the dry areas, and an increase of 0 to 50% in the wetter areas, from 1993 to 1995. The low vegetation cover in the dry areas may have allowed the NO_3^--N concentrations to remain high, while the greater increase in vegetation in the wetter areas may have caused the significant reduction of NH_4^+-N concentrations in 1994 and 1995 in the wells.

Very few differences were noted between years within the three water sample sources (harvested area wells, harvested area ditches, and natural area) with the Kruskal-Wallis 1 Way analysis of variance and Tukey Type Multiple Comparisons tests. Besides the decrease in NH_4^+-N concentrations in the well samples as previously discussed, the only other two chemical components with differences between years were pH and Cl^-. Water pH was significantly higher in the ditches in 1991 compared to 1994, and the 1994 Cl^- concentrations were significantly higher in wells compared to 1993 and 1995 concentrations. The reasons for these particular yearly differences are unclear. With these exceptions, no other significant differences were found between years for the chemical components of the three water sources.

Calculated coefficients of variation for the three water sources showed some, mainly minor, differences among years for the chemistry ranking. As the size of n varies among sampling sources, the relative order of ranking is more comparable than the actual coefficient of variation value. With all three sources, the nutrients NO_3^--N, NH_4^+-N,

SO_4^{2-}, and total Phosphorus, tended to have higher ranks for the coefficient of variation than the cations. More studies of chemical variation in other harvested and natural peatlands would be helpful to provide comparisons and address additional questions. For example, do all natural, undisturbed peatlands have low variability in the water chemistry components? Are there changes in chemical variability in harvested sites, perhaps starting at one level with the completion of harvesting, increasing as rewetting begins with the resulting mixture of wet and dry areas, then decreasing to become more comparable to undisturbed peatlands as restoration of the entire site occurs? Also, why do nutrients vary more than cations?

3.5.2 Peat chemistry

Peat chemistry of the natural area was similar to other undisturbed bogs reported in the literature (Zoltai and Johnson 1987; Nicholson 1993). The chemical concentrations in the natural area were generally lower than in the harvested area, and no significant differences between years were found in the natural area. The peat chemistry was more variable between years in the harvested area, with almost all the studied chemical components having some significant differences between years. Although not all years showed significant differences between the harvested and natural areas, all but three elements had significant differences during the study period.

Many of the chemical elements were higher in the harvested site than in the natural area, due to the removal of the ombrotrophic bog peat and the exposure of the more minerotrophic fen peat. Conductivity, pH, Ca, Mg, available NO_3-N, S, and bulk density all had significantly higher values in the harvested area than in the natural site. Peat pH and conductivity have been shown to increase with increasing depth in peat cores (Mörnsjö 1968), as has sulfur (Zoltai and Johnson 1987). Peat pH, and conductivity, Ca, Mg, S, and bulk density have also been documented to be higher in fens than in bogs (Zoltai and Johnson 1987; Nicholson 1993).

In contrast, concentrations of P and K in the peat were lower in the harvested site compared to the natural site. Higher concentrations of P and K in the natural area were due to the biological activity of *Sphagnum* concentrating these elements in the surface layers (Mörnsjö 1968; Lähde 1969; Damman 1978; Hemond 1980). Harvesting of these surface peat horizons has removed these higher surface concentrations from the post-harvested site.

In the peat, another two nutrients affected by harvesting were KCl-extractable (available) NO_3-N and NH_4-N. The harvested site had significantly higher concentrations of available NO_3-N compared to the natural area. Available NH_4-N concentrations tended to be higher in the harvested area, but not significantly higher than the neighbouring natural area. As previously suggested in chapter 2, these higher concentrations of NO_3-N and NH_4-N in the post-harvested peat may be due to a variety of factors including increased pH, aeration, microbial activity, and low vegetation cover.

Changes in nitrogen concentrations have occurred over the study period. Concentrations of available NO_3-N significantly decreased in the harvested field in 1995 compared to 1992 and 1993 concentrations, while concentrations of available NH_4-N remained unchanged during this period. The distribution of nitrogen also changed across the site, as shown by 1992 and 1995 concentration maps. In 1992, wetter areas of the harvested site in the south had higher NH_4-N concentrations and lower NO_3-N concentrations, while drier areas in the north end of the field had higher NO_3-N concentrations and lower NH_4-N concentrations (see chapter 2, Figure 2-5). Between 1992 and 1995, soil moisture increased. High moisture values were not solely found in the lower southern half of the field, but rather in the central and southeastern portions of the site (Figure 3-5). In these wet areas, available nitrate-nitrogen concentrations were low, while available ammonia-nitrogen concentrations were high. High water levels can restrict the process of nitrification, by reducing oxygen concentrations available for microbial activity (Williams and Crawford 1983). Perhaps the proportion of ammonifying and nitrifying microbial populations have changed with the changing moisture condition. Zimenko and Misnik (1970) noted that field sites with lower water levels had higher concentrations of nitrate and nitrifying bacteria, and lower concentrations of ammonia and ammonifying bacteria. Although microbial activity may help to explain the nitrogen distribution observed on the site, microbes and microbial processes were not studied here.

The 1992 maps show a clearer relationship of nitrogen concentrations and soil moisture, probably due to the lower vegetation cover in 1992 (data not shown). Although the vegetation cover remained low overall on the harvested site during the study period, randomly placed permanent control plots showed a mean annual vegetation cover increase of 0 to 50% in the wetter areas, from 1993 to 1995. Thus the wetter, vegetated areas had lower NH_4-N values than expected, although overall numbers were not significantly different from previous years.

The changes of decreasing nitrate-nitrogen concentrations in the peat are contrary to the changes found in the well samples. While available NO_3-N concentrations in the peat significantly decreased in latter part of the study and available NH_4-N concentrations remained unchanged in the harvest area peat, the well samples had a significant decrease in NH_4^+-N in the latter two years of the study, while NO_3^--N concentrations had no significant changes. Increasing water levels on the site may have reduced nitrification rates, while increasing vegetation cover in the wetter areas may have consumed some of the excess available NH_4-N in the peat, and decreased concentrations of NH_4^+-N in the water.

The peat chemistry of harvested sites is more variable compared to natural sites (Chapter 2). The present chapter shows that the peat chemistry of this harvested site was also quite variable between years. The restoring site is a dynamic, rapidly changing system, with increasing water levels and vegetation cover affecting the peat chemistry.

The changes in the harvested site formed complex changing patterns in the peat chemistry, for the only identified trends were in the nutrient concentrations of available NO_3-N and available NH_4-N. In contrast to the peat chemistry yearly variation, few significant differences were noted between years in the water chemistry analyses. The highly variable water levels across the field (see chapter 4) may have affected the peat chemistry results more significantly than the water chemistry data.

Although many significant differences between years were shown with the Kruskal-Wallis 1 Way analysis of variance and Tukey Type Multiple Comparisons tests, the coefficients of variation showed the relative variability of peat chemistry components was similar among years. In addition, both the harvested and natural areas had the same mean ranking order, with the exception that the harvested site had Na as the element with the highest relative variability, and the natural peatland had Na as the least variable element. In both sites, the nutrients available NO_3-N and available NH_4-N had high ranks of variation. As noted earlier, more studies with other sites for comparisons would be helpful for drawing further conclusions.

3.6 Conclusions

Peat harvesting of this site has altered the water and peat chemistry with the removal of the surface bog peat, moving the site back in the fen to bog succession time sequence. The post-harvested site is more similar to a moderate-rich fen in water and peat chemistry than the bog that it was originally. The exposure of fen peat has resulted in significantly higher concentrations for almost all the water and peat chemical components compared to the neighbouring natural bog.

This study found no significant differences between years in the water and peat chemistry within the natural area. A few significant yearly differences were found in the harvested area water chemistry, while the harvested area peat chemistry had many significant yearly differences. Varied conditions with changing water levels and increasing vegetation cover may have helped to form the intricate changing patterns in the peat chemistry. The yearly variation in the harvested site illustrates the importance of ongoing chemistry analyses as site restoration progresses.

Several patterns were noted in the nitrogen concentrations in the harvested field. First, the harvested site had significantly higher concentrations of aqueous NH_4^+-N and NO_3^--N, and available NO_3-N in the peat, compared to the neighbouring natural area. A variety of possible factors, such as increased aeration, high pH values, and low vegetation cover may account for these high nitrogen concentrations. Secondly, peat nitrogen concentrations appear to be affected by soil moisture. Harvested areas with high soil moisture had high concentrations of available NH_4-N and lower available NO_3-N concentrations, while drier areas had high concentrations of available NO_3-N and lower available NH_4-N concentrations. Third, the concentrations of these nutrients in the harvested area did not remain static over the years. In the peat, available NO_3-N concentrations were significantly reduced in 1995, and in the well samples NH_4^+-N was significantly reduced in 1994 and 1995, compared to earlier years. Increasing water levels and vegetation cover on the harvested site may have caused these significant reductions.

The goal of harvested peatland restoration is to restore the site to a functioning peatland ecosystem, preferably to the original peatland type. This research shows that the chemistry of the harvested site has significantly changed from the original bog ecosystem. As the site is more similar to a moderate-rich fen, ombrotrophic bog species are unlikely to thrive on this site. Instead fen species should be planted, with a focus on transitional *Sphagnum* species. Transitional fen species could help consume the available nutrients and elements, and acidify the site. Thus, the process of fen to bog succession could be initiated, and chemistry concentrations and annual variation could be reduced to natural concentrations.

Table 3-1. Water chemistry for the harvested and natural sites, means (and ranges).

		n	pH	Corr. conductivity (µS/cm at 20 oC)	TP (mg/L)	NH4+-N (mg/L)	NO3--N (mg/L)
Natural area, pipe and hollows	1993	2	3.7 (3.7)	0.0 (0.0)	0.06 (0.04-0.08)	0.05 (0.05)	0.01 (0.00-0.01)
	1994	2	3.7 (3.7-3.8)	28.1 (27.1-29.1)	0.06 (0.03-0.10)	0.08 (0.05-0.10)	0.01 (0.01)
	1995	2	3.7 (3.7)	0.0 (0.0)	0.08 (0.06-0.10)	0.04 (0.03-0.06)	0.01 (0.01)
Harvested area, ditches	1991	2 *	6.1 (5.5-8.7)	48.6 (20.5-250.8)	0.18 (0.15-0.22)	1.68 (1.55-1.81)	0.26 (0.25-0.28)
	1992	5 ^	6.0 (5.1-6.6)	73.7 (37.8-267.7)	0.16 (0.05-0.34)	0.19 (0.13-0.34)	0.02 (0.01-0.07)
	1993	3	5.6 (5.2-6.6)	39.6 (20.4-61.3)	0.09 (0.07-0.14)	0.26 (0.05-0.66)	0.03 (0.01-0.05)
	1994	4	5.2 (4.8-5.7)	89.7 (59.3-162.0)	0.14 (0.06-0.31)	0.63 (0-1.12)	0.01 (0.01-0.02)
	1995	4	5.6 (5.5-5.9)	47.7 (31.6-83.2)	0.14 (0.07-0.25)	0.82 (0.08-2.52)	0.02 (0.01-0.02)
Harvested area, wells	1993	10	5.6 (4.9-6.5)	55.5 (40.2-90.3)	0.74 (0.30-1.07)	6.61 (2.66-9.43)	0.32 (0.01-2.65)
	1994	10	4.9 (4.3-5.9)	105.5 (46.8-251.9)	0.43 (0.09-1.26)	1.00 (0-4.48)	0.01 (001-0.02)
	1995	10	5.0 (4.3-6.5)	58.5 (26.1-118.9)	0.38 (0.10-0.61)	1.97 (0.18-5.16)	0.24 (0.01-2.15)

Notes * n=15 for pH and conductivity. ^ n=14 for pH and conductivity.

Corr. conductivity=corrected conductivity. TP=total phosphorus

Table 3-1 Continued. Water chemistry for the harvested and natural sites, means (and ranges).

		n	Na+ (mg/L)	K+ (mg/L)	Ca2+ (mg/L)	Mg2+ (mg/L)	SO42- (mg/L)	Cl- (mg/L)
Natural area, pipe and hollow	1993	2	0.99	0.20	3.00	1.14	2.35	0.45
			(0.90-1.08)	(0.15-0.25)	(2.82-3.17)	(1.14)	(1.85-2.85)	(0.41-0.49)
	1994	2	0.71	0.71	2.64	0.94	0.00	0.98
			(0.62-0.79)	(0.51-0.91)	(2.52-2.75)	(0.83-1.05)	(0.00)	(0.95-1.01)
	1995	2	0.72	0.39	2.23	1.02	3.60	0.59
			(0.67-0.76)	(0.37-0.41)	(2.14-2.32)	(0.93-1.11)	(3.28-3.91)	(0.40-0.77)
Harvested area, ditches	1991	2	3.65	2.51	14.06	3.96	---	---
			(3.33-3.96)	(2.38-2.63)	(9.72-18.39)	(3.06-4.86)		
	1992	5	3.38	2.42	8.44	3.37	---	---
			(1.77-4.69)	(1.67-3.53)	(2.34-13.98)	(0.90-4.92)		
	1993	3	4.33	2.35	15.61	5.86	10.42	0.85
			(2.94-6.42)	(1.50-3.79)	(8.75-28.12)	(1.96-11.87)	(2.00-26.68)	(0.66-0.97)
	1994	4	4.46	3.87	11.00	4.16	16.42	1.35
			(3.36-5.44)	(2.83-4.32)	(5.74-19.6)	(2.62-6.73)	(2.10-57.64)	(1.28-1.46)
	1995	4	5.46	3.19	12.62	4.99	13.90	1.23
			(1.92-9.76)	(0.98-4.62)	(6.32-19.75)	(3.70-6.99)	(1.47-48.54)	(0.56-2.17)
Harvested area, wells	1993	10	8.48	2.77	13.39	3.89	8.02	0.98
			(2.82-13.92)	(1.77-3.80)	(7.84-28.70)	(0.77-8.67)	(1.34-18.72)	(0.56-1.60)
	1994	10	6.00	3.18	12.47	4.63	8.11	2.05
			(3.04-14.16)	(1.67-4.99)	(5.95-28)	(2.76-8.66)	(0-20.72)	(1.16-4.84)
	1995	10	7.27	2.57	15.84	4.96	15.30	1.08
			(3.32-22.3)	(1.05-3.40)	(6.94-31.95)	(2.65-8.96)	(1.71-60.67)	(0.61-2.81)

Table 3-1 Continued. Water chemistry for the harvested and natural sites, means (and ranges).

		pH	Corr. conductivity (µS/cm at 20 oC)	TP (mg/L)	NH4+-N (mg/L)	NO3--N (mg/L)
Total annual mean	Natural area	3.7	9.4	0.07	0.06	0.01
	Harvested area, ditches	5.58	60.0	0.14	0.72	0.07
	Harvested area, wells	5.09	73.2	0.52	3.19	0.19

		Na+ (mg/L)	K+ (mg/L)	Ca2+ (mg/L)	Mg2+ (mg/L)	SO42- (mg/L)	Cl- (mg/L)
Total annual mean	Natural area	0.81	0.43	2.62	1.03	1.98	0.67
	Harvested area, ditches	4.26	2.87	12.35	4.47	13.58	1.14
	Harvested area, wells	7.25	2.84	13.9	4.49	10.48	1.37

Note: Natural area and harvested area wells had data from a three year period. Harvested area ditches had data from a five year period.

Table 3-2. Peat chemistry for the harvested and natural sites, means (and ranges).

		n	pH	Corr. Conductivity (µS/cm at 20 oC)	P (mg/kg)	Av. NH4-N (mg/kg)	Av. NO3-N (mg/kg)
Natural area	1992	1	4.15	9.99			
	1993	2	---	---	406.3 (387.7-424.9)	112.0 (80.2-143.8)	1.4 (0-2.7)
	1994	2	4.05 (4.0-4.1)	6.1 (4.9-7.2)	653.4 (595.7-711.1)	---	---
	1995	2 ^	4.3 (4.3)	4.7 (0-9.3)	576.6	51.8 (14.9-88.6)	0.1 (0-0.1)
Harvested area	1991	86	4.37 (3.85-7.95)	31.0 (0-245.2)	---	---	---
	1992	22 *	4.13 (3.75-6.06)	95.4 (0.5-600.4)	334.6 (187.8-584.8)	137.8 (13.5-711.6)	73.6 (0-357.2)
	1993	40	---	---	390.7 (176.2-624.0)	104.3 (26.0-440.9)	82.5 (0-433.0)
	1994	20	4.6 (4.0-5.4)	73.4 (17.5-605.7)	404.5 (161.5-570.2)	---	---
	1995	20	4.6 (4.3-5.7)	130.7 (17.1-1025.1)	370.1 (134.3-633.2)	110.9 (13.4-629.3)	17.0 (0-129.5)
Total annual mean							
Natural area			4.2	6.9	545.4	81.9	0.8
Harvested area			4.4	82.6	375	117.7	57.7

Notes: ^ n=1 for P. * n=48 for available NO3-N and available NH4-N, and 30 for pH and conductivity.

Table 3-2 Continued. Peat chemistry for the harvested and natural sites, means (and ranges).

		n	Na (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)	H2O Content (% by vol.)	Bulk Density (g/cm3)
Natural area									
	1993	2	110.2	241.6	6236	855.7	1528.7	15	0.0168
			(106.1-114.2)	(114.8-368.3)	(5615-6856)	(705.3-1006)	(974.3-2083)	(10-20)	(0.0123-0.0212)
	1994	2	117.1	825.7	2701	704.8	663.8	68	0.0467
			(114-120.2)	(652.8-998.5)	(2329-3072)	(643.4-766.1)	(603.3-724.2)	(66-71)	(0.0459-0.0479)
	1995	2 ^	112.7	809.7	2267	481.1	499.8	34	0.0367
			(14.9-88.6)					(28-41)	(0.0255-0.0479)
Harvested area									
	1992	22	562.7	331.7	6913	1213	1777.0	50	0.1341
			(64.19-3798)	(93.95-1674)	(3135-11429)	(460.1-2058)	(572.1-5751)	(26-80)	(0.0548-0.1951)
	1993	40	369.4	262.7	7952	1056.7	1861.8	33	0.0947
			(51.21-9393)	(56.71-3096)	(2261-16220)	(406.5-3269)	(569.6-11740)	(10-72)	(0.0341-0.1501)
	1994	20	376.3	356.5	9584	1501	2073.4	60	0.0967
			(49.6-4352)	(112.6-1606)	(4734-15141)	(769.7-3019.0)	(870.0-7408)	(21-98)	(0.0408-0.1714)
	1995	20	523.9	244.1	8556	1258.9	2015.0	70	0.1160
			(102.0-6785)	(93.0-935.5)	(4286-16165)	(682.8-2832)	(601.5-8127)	(33-99)	(0.0263-0.1766)
Total annual mean									
Natural area			113.3	625.7	3735	680.5	897.4	39	0.0334
Harvested area			458.1	298.8	8251	1257.4	1931.8	53	0.1104

Notes: ^ n=1 for Na, K, Ca, Mg, and S.

Table 3-3. Significant differences between groupings of the water chemistry components.

Chemical element	Significant differences between years within a sampling source	Years with significant differences between sampling sources	Significant differences between sampling sources when years are grouped together
pH	Ditches 91 92 93 95 94		D WP NA
Corrected conductivity (µS at 20 oC)			WP D NA
Na+ (µeq/L)		1993 WP D NA	WP D NA
K+ (µeq/L)		1994 D WP NA	D WP NA
		1995 D WP NA	
Ca2+ (µeq/L)			WP D NA
Mg2+ (µeq/L)			WP D NA
Total P (µeq/L)		1993 WP D NA	WP D NA
NH4+-N (µeq/L)	Water pipes 93 95 94	1993 WP D NA	WP D NA
		1995 WP D NA	
NO3--N (µeq/L)		1995 WP D NA	WP D NA
SO42- (µeq/L)			
Cl- (µeq/L)	Water pipes 94 95 93		WP D NA

Note: NA = Natural area, pipe and hollows, D = Harvested area, ditches, WP = Harvested area, water pipes

Table 3-4. Significant differences between groupings of the peat chemistry components.

Chemical element	Significant differences between years within the harvested site	Years with significant differences between the natural and harvested area
pH	94 95 91 92	1994*
Corrected conductivity (µS/cm at 20 oC)	95 92 94 91	1994* 1995*
Na (mg/kg)	92 94 95 93	
K (mg/kg)	94 92 95 93	
Ca (mg/kg)		1994*
Mg (mg/kg)	94 95 92 93	1994*
P (mg/kg)		1994*
Available NH4-N (mg/kg)		
Available NO3-N (mg/kg)	93 92 95	1993*
S (mg/kg)		1994*
Water content (% by volume)	95 94 92 93	1995*
Bulk Density (g/cm3)	92 95 93 94	1993* 1994* 1995*

Note: Significance values are * for 0.05 significance.

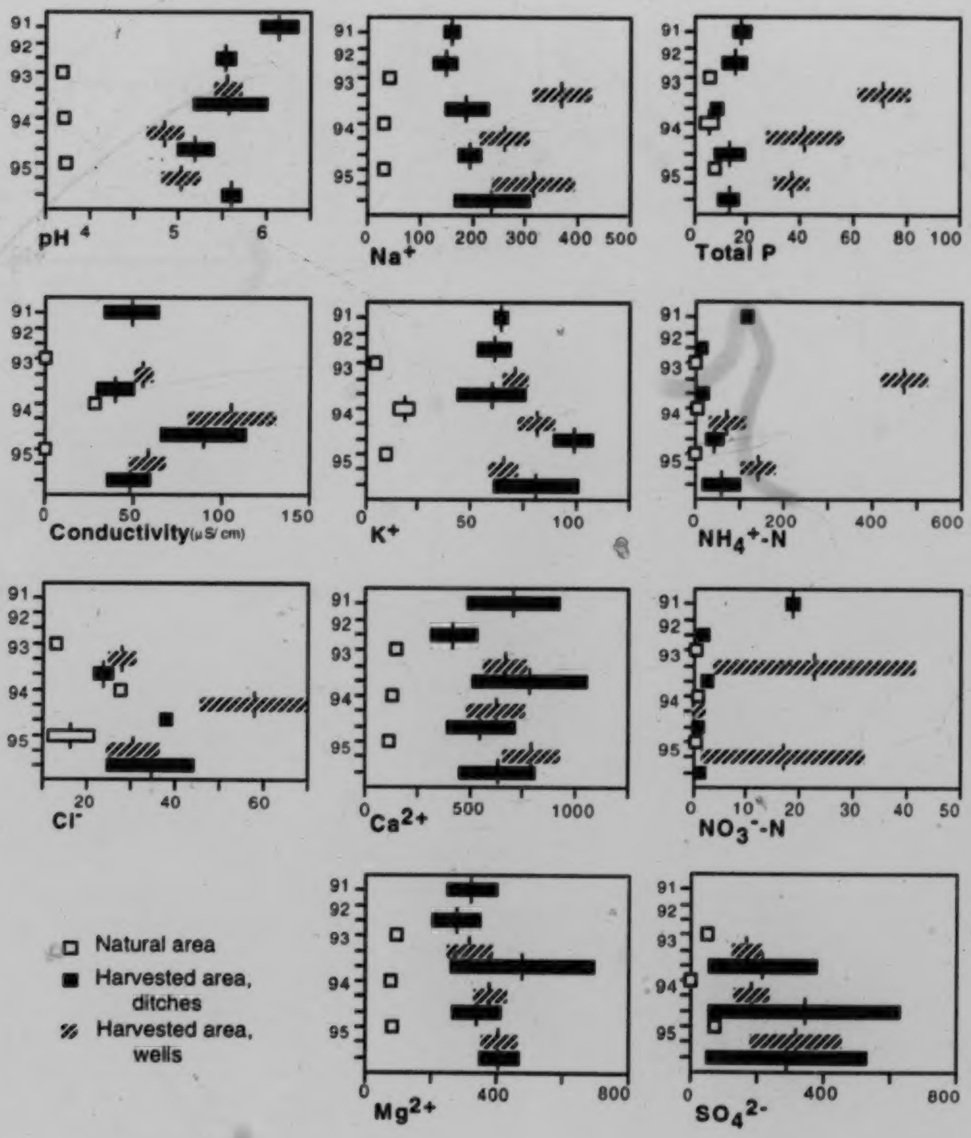


Figure 3-1.
Annual mean water chemistry (in µeq/L, +/- 1 SE), 1991-1995 values

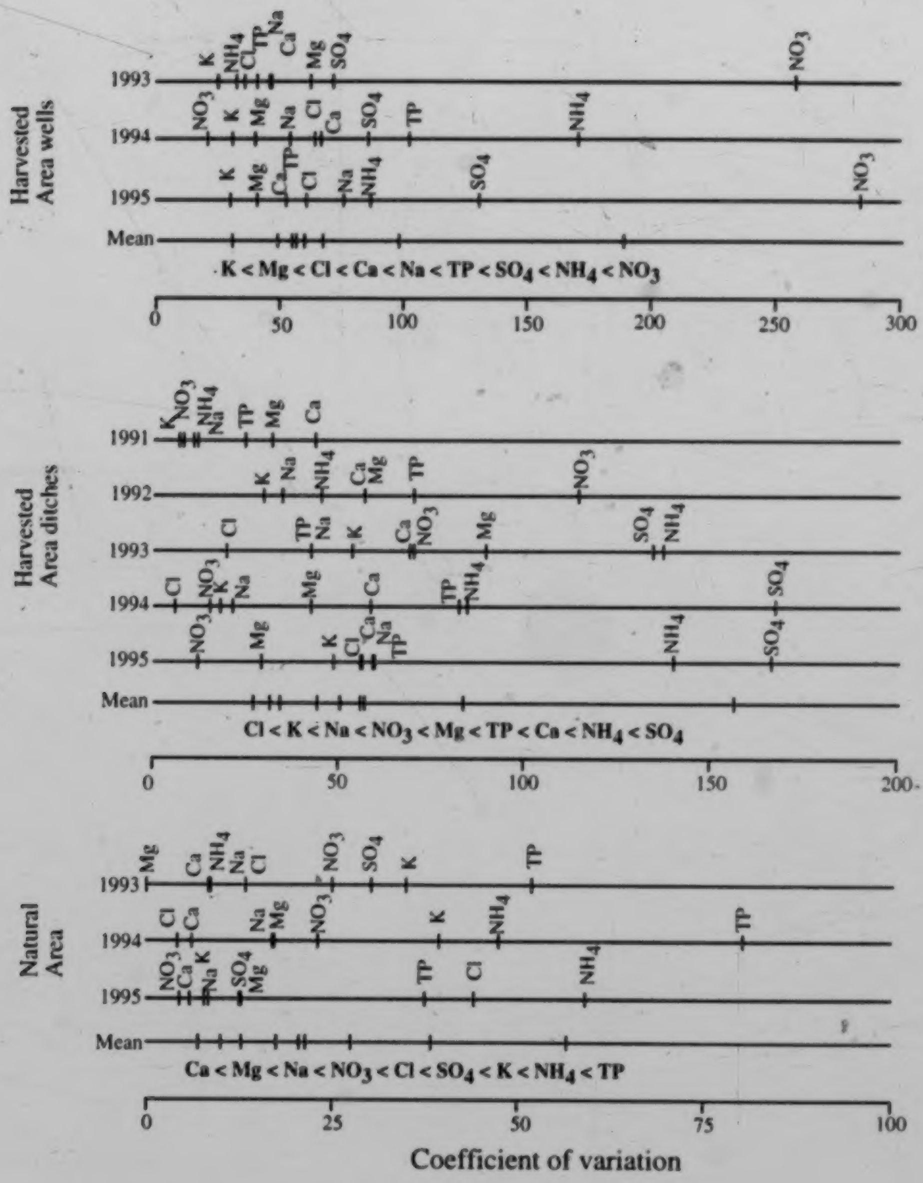


Figure 3-2. Coefficients of variation for water chemistry components for natural and harvested areas. Annual and total mean annual values outlined. Abbreviations: Ca=Ca^{2+}, Cl=Cl^-, K=K^+, Mg=Mg^{2+}, Na=Na^+, NH_4=NH_4^+-N, NO_3=NO_3^--N, SO_4=SO_4^{2-}, TP=total Phosphorus.

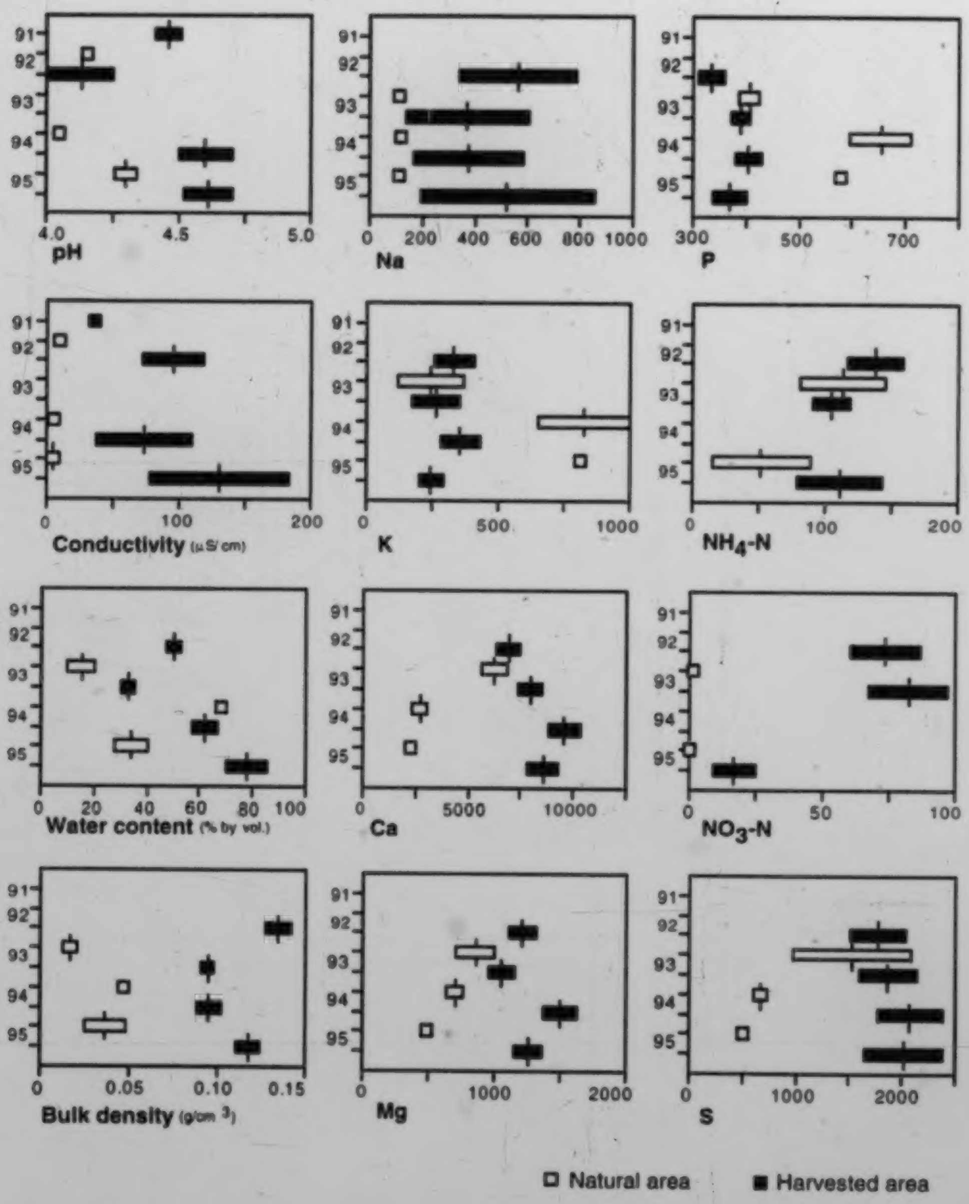


Figure 3-3.
Annual mean peat chemistry (in mg/kg, unless otherwise noted, +/- 1 SE), to 5 cm depth, 1991-1995 values.

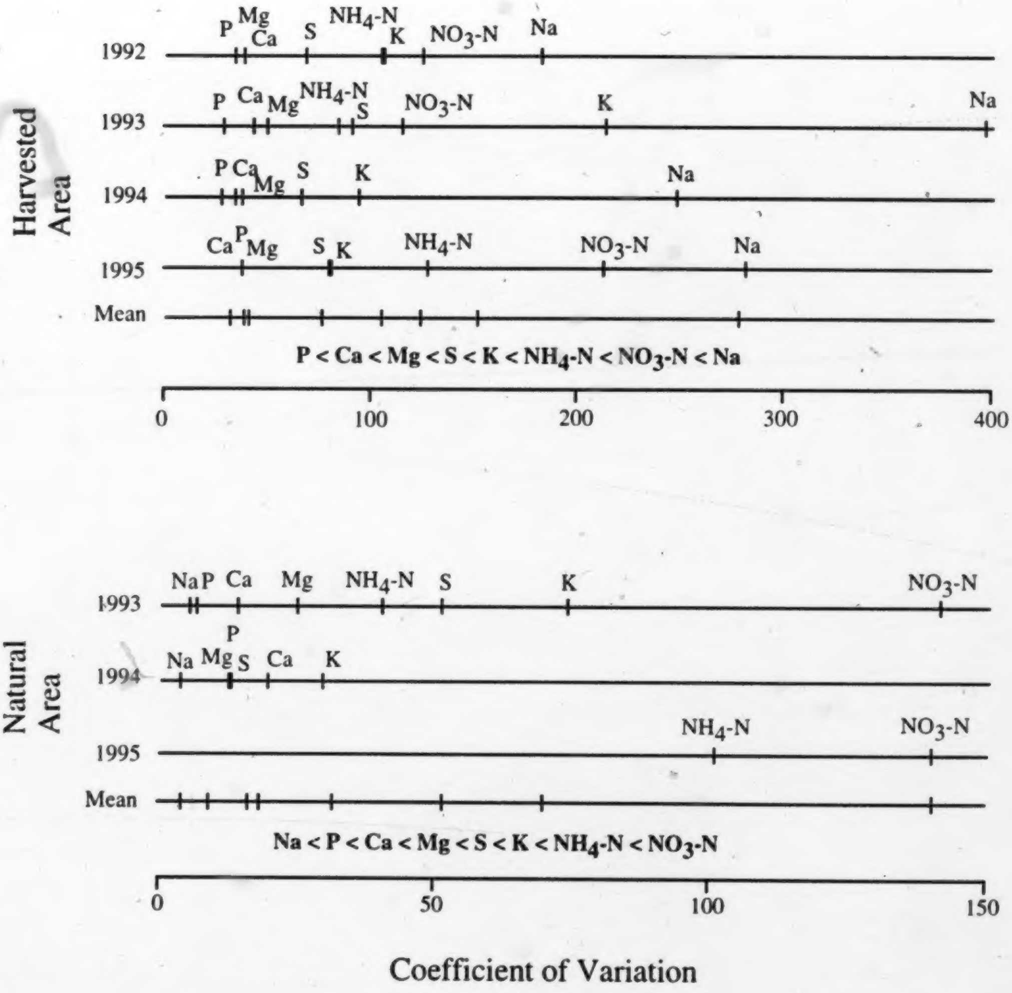
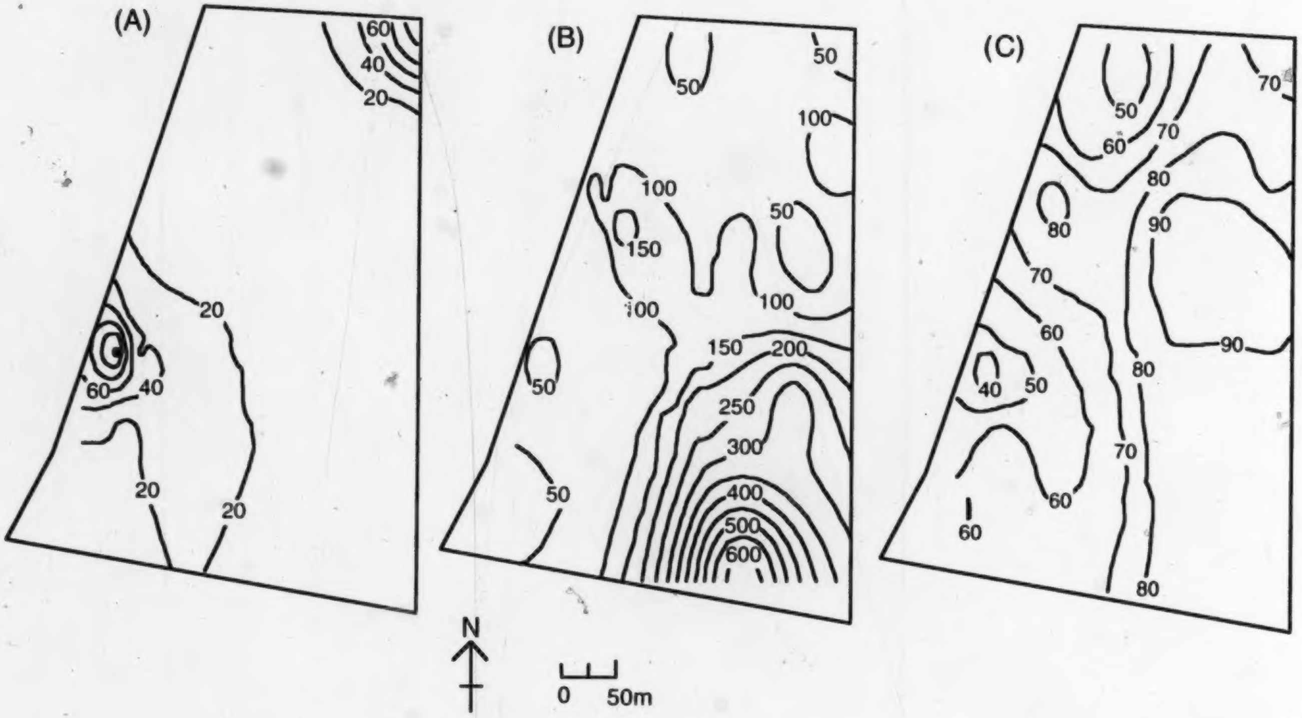


Figure 3-4. Coefficients of variation for peat chemistry components for natural and harvested areas. Annual and total mean annual values outlined.


(A)
60
40
20
20
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(B)
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300
50
400
500
600
(C)
50
70
60
70
80
80
90
70
60
90
80
40
50
70
60
60
80
N
0
50m

Figure 3-5. (A) Available nitrate-nitrogen, (B) available ammonia-nitrogen across the harvested site (in mg/kg, to 5 cm depth). (C) Soil moisture (% by volume) across the site. July, 1995 values.

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Chapter 4

Changing water levels in a harvested and natural peatland and their relevance to restoration

4.1 Introduction

Peatlands are unique ecosystems in which partially decomposed organic material accumulates over time in water logged areas. Peat and water interact, and both are important to the functioning and maintenance of a peatland. An undisturbed peat column contains upper and lower zones, termed the acrotelm and the catotelm, respectively. This two zone, or diplotelmic view of peatland hydrology was developed by E.A. Lopatin, K.E. Ivanov and H.A.P. Ingram and was summarized by Ingram (1978, 1983). The acrotelm is the upper layer in which peat is actively forming and in which the water table fluctuates. Periodic aeration occurs with water level fluctuation, and much of the biological activity in the peat deposit occurs in this zone. The peat is loose and fibric in this layer, with a low bulk density. The peat has large pores, decreasing in size with increasing depth. The pores allow for a large detention storage capacity at saturation, a small capillary fringe flux, and high saturated hydraulic conductivity especially near the peat surface (Romanov 1968).

The catotelm is beneath the acrotelm and is the region that is continuously water logged. Biological activity is limited and decomposition rates are slow in this anaerobic zone. The peat is compacted, usually more humified, and has a higher bulk density. Pore size is smaller, resulting in lower permeability and lower detention storage capacity (Boelter 1964; Ingram and Bragg 1984).

These two zones interact and stabilize each other. The acrotelm helps to preserve the catotelm by moderating water levels with its large detention storage capacity and high hydraulic conductivities. The catotelm retains the large volume of water below the acrotelm by impeding drainage due to its low permeability (Ingram and Bragg 1984).

Harvesting of a peatland for horticultural peat destroys the balance between the acrotelm and the catotelm, and negatively affects the hydrology of a peatland. Ditches drain the peatland, and the surface vegetation and the fibric *Sphagnum* bog peat are removed. The removal of the surface vegetation and upper peat destroys the functioning acrotelm. The site is no longer diplotelmic with the two zones of the acrotelm and the catotelm, but rather becomes haplotelmic, with only the catotelm remaining. The exposed catotelm peat is more decomposed and compacted, and has reduced detention storage capacity and lower hydraulic conductivity (Schouwenaars 1993a). Water levels are often low and more variable (Bragg 1995). Low water levels further compound the hydrological problems by allowing more surface peat to decompose, which further decreases pore size, permeability, detention storage capacity and hydraulic conductivity (Ivanov 1975; Schouwenaars 1993a; Heathwaite 1995).

Although drained, harvested and rewetted peatlands have been studied in Europe and Britain (Eggelsmann 1988; Schouwenaars 1988; Joosten 1992; Schouwenaars and Vink 1992; Bragg 1995; Heathwaite 1995), little work has been done to investigate the hydrology of harvested and restoring peatlands in Canada. The objective of this chapter is to investigate how hydrological properties of a harvested site compare with an associated natural peatland at a site in Alberta. Water levels were specifically examined in the two areas to address the following questions.

1/ Were water levels in the harvested site similar to water levels in the neighbouring natural peatland? Were the annual mean water levels and annual amplitudes similar between the two areas?

2/ How have water levels reacted to the partial removal of the peat deposit with harvesting?

3/ Did the water levels change over the four year study period? Were water levels in the harvested site stabilized, aided by such rewetting measures as the installation of stationary and adjustable dams?

4/ How could water levels be improved on harvested sites?

4.2 Site description

The Seba Beach peatland is located about 130 km west of Edmonton, Alberta (53°33'N, 114°44'W; Figure 4-1). This peatland is classified as a Continental Mid-Boreal peatland (NWWG 1986). The area has a mean annual temperature of 2.4 °C, with a mean January temperature of -15 °C and mean July temperature of 16 °C. Annual precipitation for the area is 528.8 mm, with a quarter of the total precipitation falling as snow (Environment Canada 1982a, 1982b).

The natural peatland is located along the western edge of the harvested site. The vegetation is mainly composed of *Picea mariana*, *Ledum groenlandicum*, *Andromeda polifolia*, and *Sphagnum* mosses such as *Sphagnum fuscum*, *S. magellanicum*, and *S. angustifolium*. A site description of a section of the natural area is outlined in Li and Vitt (1997).

Originally the harvested peatland was covered by bog and poor fen vegetation dominated by *Picea mariana*, *Sphagnum fuscum*, *S. magellanicum*, *S. angustifolium*, and scattered *Larix laricina*. This site was first opened in 1975 to harvesting by dredging. In 1980, Fisons Horticulture Inc., now Sun Gro Horticulture Canada Ltd., acquired the site and leveled, drained, and then vacuum harvested the area. The restoration site is approximately 16 hectares in area, 0.02% of the area presently being harvested. The peat surface is highest in the northeastern corner, sloping downward to the southwest corner, with drainage southwestward. Drainage ditches run east/west, dividing the field into 20 harvesting bays. The perimeter ditch runs along the western edge. Peat depth ranges from 0.73 m at the northern end, deepening at the southern end to over 4 m.

4.3 Materials and methods

4.3.1 Rewetting measures

When harvesting ceased in the fall of 1991, a dam of compacted peat and roots was constructed in the perimeter drainage ditch, at the southwestern corner of the site. In the spring of 1992 one ditch on the northern side, and two ditches on the western side were dug to introduce more water from the surrounding natural peatland area. These ditches did not bring in great quantities of water, and the two western ditches were refilled in 1993 so as not to further impact the neighbouring natural area. The northern ditch was in an area already affected by other harvesting and did bring in some water, and thus was left open.

In the spring of 1992, some of the lower, southern portions of the harvested site were wet, but much of the higher, northern area was still dry. To regulate the distribution of water over the site for more even rewetting, five secondary adjustable wooden dams were installed in July 1993 (see Figure 4-1). As the water levels increased on the site over the years, peat and roots were compacted behind each secondary dam in an effort to stop ditch edge erosion.

4.3.2 Water level monitoring

To monitor water levels at the harvested site and in the neighbouring natural area, wells were constructed of 100 mm PVC pipes. The pipes were 1.5 to 2.0 m long, and slotted along their length. Wells were installed in the spring of 1992 (see Figure 4-1, site locations Bay 5-1, Bay 15-1 and Bay 18). The natural area well was located over 200 m away from the southwestern corner of the harvested area, to avoid any drainage influence from the harvested area. A Stevens F continuous automatic water level recorder was installed in the natural area and in the harvested area (site location Bay 15-1). Nine more wells were set up in the summer of 1993, along a north/south transect of the western side of the harvested site. Water level measurements were taken approximately weekly during the growing season, and occasionally during the winter months from 1992-1995. Water levels were measured with a meter long wooden measuring rod, painted flat black, with a plastic coated measuring tape attached to one end of the rod, to extend the measuring length for water levels below one meter. Well elevations were surveyed in the fall of 1993, 1994, and 1995 from a stable base point outside the field site. At these times, the well elevations above the ground surface were also recorded to calculate ground level. The 1994 survey showed that the ground elevation in two depressional areas was rising. Slight movements in the well elevations were also noted. To take into account this well and ground movement, well height above the peat surface was recorded with each water level measurement in 1995.

4.3.3 Rainfall measurements

To record rainfall in the harvested and natural areas, a wedge shaped Trucheck rain gauge was installed in both areas, close to the automatic water level recorders. The gauge in the natural area was set up in a cut line intersecting the natural area, to avoid the effects of trees. The gauges were set out during the frost free months.

4.3.4 Bulk density measurements

Bulk density measurements were taken from surface peat samples, as outlined in chapter 3.

4.4 Results

4.4.1 Bulk density

Surface peat (0 - 5 cm) on the harvested site had higher bulk densities than the bulk densities from the peat in the neighbouring natural area (Table 4-1). The overall mean of the harvested area bulk density is 0.1079 g/cm^3 and within the range designated for mesic peat (Table 4-2). No trends were observed between years. Surface peat of the natural area had a much lower mean bulk density of 0.0334 g/cm^3, and in the range of fibric peat.

4.4.2 Harvested area mean annual water levels and amplitudes

The four years of study can be divided into two parts, the dry years and the wet years. Precipitation levels were low in the first two years, approximately 15 - 20% lower than the 30 year mean for the area. In the second half of the study, precipitation levels were higher than the 30 year mean (Table 4-3).

In the dry years, the harvested site generally had low water levels (Bay 5-1 and Bay 15-1, Figure 4-2). Annual mean water levels for these two locations were approximately 85 and 70 cm below the surface (Figure 4-3). Yet even in the dry years, water was accumulating in lower areas of the field. Well Bay 18 was in depressional area that was one of the first areas to rewet as water backed up from the primary dam. Water levels here were above or close to the ground surface for 1992 and 1993 (Figure 4-3). Thus water levels were spatially variable across the field during the dry years, as water levels ranged from -123 cm to +44 cm.

In 1994, the first wet year, water levels rose across the harvested site due to a deep snow pack in the winter of 1993-94, the high precipitation levels during the growing season, and the dams which helped to retain water on the site (Figure 4-3). The large rise in water levels was reflected in the high range of amplitudes across the harvested site in 1994. Water level amplitudes, the distance of lowest to highest water level at one well, varied from 0.5 m to over a meter (Table 4-4). Although water levels rose in all areas of the site, some areas were still dry, while other areas were flooded (Table 4-3). In the second wet year, 1995, mean water levels were similar to 1994 levels in the harvested area, while the range of water level amplitudes decreased (Table 4-3). Higher over wintering water levels in 1995 decreased the annual amplitudes. Water levels continued to be spatially variable across the field during the wet years, with water levels ranging from -133 cm to +83 cm in 1994, and from -99 cm to +70 cm in 1995.

4.4.3 Natural area mean annual water levels and amplitudes

In the natural area, water levels were more consistent within and between years than the harvested area (Figure 4-2). In the dry years, annual mean water level was approximately -20 cm. Increased precipitation in 1994 increased the annual mean water level to -6 cm, while annual water level amplitude decreased (Figure 4-3, Table 4-3). This decrease in variation in the natural area contrasts with an increase in variation in the harvested area in 1994. In 1995, water levels in the natural area remained similar to 1994 levels (Table 4-4). In all the years of study, the natural area water levels did not exceed the range of +1 cm to -40 cm below the moss surface.

4.4.4 Influence of precipitation events in the natural and harvested area

Continuous water level recording in the natural area and harvested area (location Bay 15-1, Figure 4-1) documented how water levels in the two areas reacted to precipitation events during the growing seasons of 1992-1995 (Figures 4-4 and 4-5).

In the first dry year, precipitation levels were low, with few major rain events. The harvested area and natural area had similar water level amplitudes. Yet water levels at well Bay 15-1 were approximately half a meter lower than water levels in the natural area (Figure 4-4). Both sites reacted to a large rain event in September with increasing water levels, with the harvested site rising 10 cm higher than the natural area. Water levels decreased to a greater extent in the harvested site than the natural area during the following two months.

The second dry year had lower than average precipitation levels, with a few scattered major rain events during the summer. In response to these rain events, water levels in the harvested area rose dramatically. Water levels in the natural area were fairly steady, with only slight rises corresponding to the steeper peaks in the harvested area (Figure 4-4). Water level amplitude at well Bay 15-1 was twice as much as in the natural area. Once again, harvested area water levels decreased more sharply than natural area water levels in the late summer and fall, as precipitation decreased.

After two dry years, precipitation amounts increased in 1994. With higher precipitation levels, natural area water levels were steady and close to the ground surface (Figure 4-5). Natural area water level amplitude during the growing season was a quarter of amount compared to the previous dry years. At well Bay 15-1 in the harvested area, water levels rose with the summer rains, from - 66 cm up towards the ground surface in July. From this high point water levels dropped, with only small increases in response to some rain events (Figure 4-5). Compared to the natural area, this well had a water level amplitude eight times higher.

In the second wet year, the natural area water levels remained close to the peat surface. At well Bay 15-1 well in the harvested area, water levels were later in rising due to delayed summer rains. Much of growing season's rain fell in August, resulting in a 50 cm increase in water levels at well Bay 15-1, ten times the water level increase in the natural area. Over the growing season, water level amplitude was three and half times greater at well Bay 15-1 compared to the natural area. Water levels for both locations remained close to the peat surface during the month of September.

4.4.5 Harvested area water levels within the range found in natural peatlands

In the natural area, water levels did not drop lower than 40 cm from the moss surface, or higher than 1 cm above. The idea that restored bogs should not have water levels greater than 40 cm below the peat surface during the growing season, to ensure an adequate water supply for evapotranspiration, is generally recognized (Schouwenaars 1988; Verry 1988). Over the study period, harvested area water levels were not often within the range found in the natural area. In the two dry years, 0 % (1992) and 41 % (1993) of the recorded harvested area water levels fell within the natural range (Table 4-

4). In the second dry year, some areas had 0% of their measured water levels within the natural range, while other regions had 100% of their recorded water levels within the natural range, indicating the spatial variability of water levels across the harvested field (Table 4-3). Water levels recorded outside the natural range were almost all lower than 40 cm from the peat surface in 1993.

In the first wet year, 1994, water levels rose across the harvested site, yet the percentage of measured water levels within the natural range decreased from the previous year. Some areas still had water levels greater than 40 cm below the peat surface. Other areas were flooded during the year, and therefore had water levels higher than the natural water level range. In 1995, mean water levels were similar to 1994 levels. The percentage of readings within the natural range, although still low overall at 37%, was higher than the previous year (Table 4-3).

4.4.6 Topographic movement in the harvested area

Well elevation surveys indicated yearly differences in well and ground elevation for some areas in the harvested site. Along the western quarter, the site generally sloped downward from north to south, with a slight rise in ground level over Bay 13 and 15 (Figure 4-6). The ground and well elevations remained stable in the higher areas, while they increased over the years in the depressional areas. From 1993-1995 the change in topography in the harvested area ranged from a decrease of 6 cm on the higher ground, to an increase of 47 cm in the depressional areas. The natural area showed no overall change in ground elevation during this time. Thus the harvested area was much more unstable, not only with a variable water table, but with a variable peat surface elevation as well.

4.4.7 Effectiveness of the rewetting measures

The primary peat dam and secondary adjustable wooden dams did help to retain water on the site. Yet problems were experienced with both kinds of dams.

Water was retained on the site during the dry years, as little water was observed in the ditch behind the primary dam, while water piled up in front of the dam. In the wet years of 1994 and 1995, particularly during the spring time, the primary dam's effectiveness was reduced as high water levels in the ditches allowed water to flow over the top of the dam. High ditch water levels also affected the secondary dams. Water eroded the ditch edges, especially just in front of each wooden dam. Saturated peat slumped into the ditches and water was able to detour around the dams. More peat and roots were compacted behind each dam to try to stop this erosion, but sometimes the water flooded over the field and by-passed around the dams. Thus the secondary dams were only moderately successful in keeping the water evenly distributed across the site.

4.5 Discussion

4.5.1 Water level variation in the harvested area

Harvesting of this peatland resulted in lower and more variable water levels than in the neighbouring, unharvested peatland. The harvested area had greater increases in water levels due to rain events, and greater decreases in water levels during drier periods. A number of possible reasons for these differences are examined below.

With the removal of the acrotelm during peat harvesting, the harvested site was left with more compacted, more mesic peat exposed, as reflected in the higher bulk density measurements. The higher bulk density measurements indicate that this peat has smaller pores and a lower detention storage capacity. Water input results in greater water level rises due to the filling of these small pores.

In addition to smaller pores and lower detention storage capacity, high water level fluctuations on the harvested site could be due to increased water loss through evaporation, or surface and subsurface runoff from the site.

Little research has been done on evaporation rates of harvested peatlands. The capillary fringe is known to have a greater thickness in a harvested site than in an undisturbed acrotelm. The smaller sized pores in the remaining peat in a harvested site have high matric forces, which results in the thicker capillary fringe (Romanov 1968; Ingram 1992; Schouwenaars 1992). A larger capillary fringe in the harvested area allows water to be drawn from lower levels with evaporation, thereby further reducing water levels during dry periods compared to the undisturbed peatland.

A few direct evaporation measurements have been recorded on harvested sites. From sites in Britain and Europe, Heathwaite (1995) has recorded higher evaporation rates on disturbed, drained peatlands compared to natural peatlands. She attributed these higher evaporation rates due to trees and scrub vegetation invading the sites and drawing water from the deeper peat layers. Price (1996) studied a disturbed site which was essentially devoid of vegetation. With only the peat surface removed by block cutting and the ditches blocked, evaporation rates were similar, yet slightly higher in the harvested area than in a neighbouring natural area. Generalizations from these limited studies cannot be appropriately applied to the Seba Beach site due to climatic and vegetation differences between the study sites, and the wide variety of vegetative and soil moisture conditions across the Seba Beach harvested site.

Another possible reason for increased water losses at the harvested site may be subsurface drainage. Heathwaite (1995) stated that subsurface drainage usually becomes more important relative to surface runoff in disturbed peatlands. Vertical seepage losses may increase with the reduction in the peat deposit depth, as subsurface seepages have been correlated to thickness and permeability of the peat layer (Schouwenaars et al. 1990). Yet Schouwenaars (1993b) has stated that less humified peat over 1 meter in depth often isolates a harvested peatland hydrologically. Although no specific subsurface hydrological measures were made on the harvested site, all but one of the peat depth measurements were over a meter, and ditch bottoms did not reach the mineral surface, so subsurface water losses should be low.

Surface runoff was observed on both the harvested and natural areas. In the spring seasons of 1994 and 1995, overland flow was observed coming down from the more elevated natural area. Also during these times, water flowed over the primary dam at the lower end of the harvested site. Measurements were not recorded to discern the relative amounts of surface runoff from each site.

4.5.2 Water level variation in the natural area

Compared to the harvested site, the neighbouring natural peatland had less water level fluctuation. Water levels did not go below -40 cm or above 1 cm above the peat surface, during the four years of recording. The higher precipitation amounts in 1994/1995 resulted in less water level fluctuation, smaller water level amplitudes, higher mean annual water levels, and higher minimum water levels in the natural area, compared to the harvested area (Table 4-3).

The smaller water level fluctuations in the natural area illustrate the buffering effect of an intact acrotelm. During wet periods when the pores of the acrotelm were full, excess water was carried rapidly off the peatland. The high hydraulic conductivity in the surface peat layers allowed for little surface flooding (Ivanov 1975; Table 4-2). Evapotranspiration during these times resulted in only small decreases in water level in the natural area. Due to the large pore size in the surface fibric peat, much water can be removed by evapotranspiration with only a small decrease in water level (Boelter 1964). During dry periods, evapotranspiration levels decreased as *Sphagnum* species dried and whitened, and as surface albedo increased. Evapotranspiration rates also declined as the capillary fringe fell below the root zone of peatland vascular plants, 30-35 cm below the peat surface (Romanov 1968). Conversely when the pores were not filled, major precipitation events were absorbed with small water levels rises.

4.5.3 Harvested area water levels within the natural peatland water level range

Although the harvested area had lower and more variable water levels compared to the neighbouring peatland, the increase in water levels on the harvested site was encouraging to observe, especially as moisture levels are so important to moss growth and peatland revegetation. Rewetting measures of the dams helped retain water on the harvested site, but moisture levels were not consistent across the field and many areas still had water levels outside of the range found in the natural area (+1 – -40 cm) (Table 4-3). The relatively small water level fluctuations found in natural sites are deemed essential for good *Sphagnum* regeneration and growth (Verry 1988). In greenhouse experiments, Campeau and Rochefort (1996) found that *Sphagnum* diaspore recolonization success was strongly dependent on water level height. *Sphagnum* growth was more rapid when water levels were 5 cm below the peat surface, compared to when water levels were 15 or 25 cm below the peat surface. Li and Vitt (1995) found that *Sphagnum* fragments established along most of a moisture gradient of dry to wet, and that establishment was restricted at both extremes of the gradient. Price (1996) stated that soil moisture and peat bulk density may be more influential on *Sphagnum* re-establishment. Surface soil moisture levels may become isolated and unrelated to water levels as water levels fall (Price in press). In addition, the surface peat has a high water tension capacity, with its small pores and high bulk density. The surface peat may hold water tightly and *Sphagnum* may not be able to extract the water unless the peat is near saturation (Price 1996; Price in press). More research is needed to explore *Sphagnum* diaspore growth in relation to soil moisture.

In the Seba Beach harvested site some areas were still too dry, while other, lower lying areas had water ponding. Although these ponds had water levels above the range found in natural sites, and may have been too deep for good *Sphagnum* growth, these ponds may help to regulate water levels across the site.

4.5.4 Ponding on the harvested site

The naturally forming ponds on the harvested site may serve as reservoirs, increasing the detention storage capacity close to the harvested peat surface. Some hydrologists have recommended mechanically creating depressions by hollowing areas (Beets 1992; Price in press), or by creating dams to collect water in areas across a harvested site (Schouwenaars 1995). These ponds help moderate water level fluctuation by reducing peak discharges in wetter periods and by acting as water sources for the peat during drier periods (Schouwenaars 1988, 1993a). The percentage of pond surface area necessary to limit water level fluctuation has been calculated to be dependent on the storage capacity of the peat, and the water levels and water loss during the summer (Beets 1992). In the Netherlands, a minimum winter depth of 20 cm for these ponds has been observed to reduce grass and tree growth (Schouwenaars 1995), while Beets (1992) has suggested an overall depth of 50-60 cm. Recommendations to limit the size of these hollows to less than 20 m in diameter have also been made, to reduce wave action disturbance of the water saturated peat (Joosten 1992), and to reduce the appeal to birds, as birds could eutrophy the area with their guano (Blankenburg and Kuntze 1988). On humified peat, these ponds should be no more than 5 m apart, due to low peat permeability (Schouwenaars 1992). Presumably, the mesic surface peat on this harvested site had higher peat permeability, and ponds could be spaced farther than 5 m apart.

Most of the ponds on this harvested site were greater than 20 m in diameter, and both waves and water birds have been observed on them. Pond water depth varied across the site and over the year. Although these flooded areas may have served as better reservoirs with reduced sizes, these areas were places where such introduced and naturally invading vegetation as sedges grew. Over time this vegetation may serve as wind and wave breaks. Introduced *Sphagnum* species grew along the bases of sedge tufts, but tended to thrive more in areas where water levels were consistently close to the peat surface, such areas as the pond edges. High nutrient levels in the pond water on this harvested site may also have inhibited *Sphagnum* growth in the ponds (Table 4-5). In more nutrient limited harvested sites where ombrotrophic peat is still exposed, this problem with nutrient rich pond water would not occur.

4.5.5 Changing topographic elevation in the harvested area

In addition to increasing water levels, rewetting of the site resulted in increasing peat surface levels. Subsidence due to dewatering has been observed in drained peatlands (Rothwell et al. 1996), and rewetting of a drained peatland allows the peat to reswell. In depressional areas where water pooled, ground elevation rose as the peat swelled. In those areas, the maximum peat surface increase was 47 cm over three years. Varying peat surface increases have been recorded on rewetted peatlands (Eggelsmann and Schwaar 1979; Blankenburg and Kuntze 1988; Mawby 1995), with a range given of

20-50 cm after several years (Eggelsmann 1988). The higher, and therefore, drier areas of the harvested site actually showed a decrease in ground elevation over three years, up to 6 cm. This decrease could be a result of wind erosion of the dry surface, and/or of increased decomposition. No clear trend of increasing bulk densities was observed in the drier areas, so it is probable that the decrease in elevation was due to wind erosion. Between rising rewetted depressional areas and eroding drier areas, some self leveling of the site may slowly occur. These changes in peat surface in the harvested site point to the importance of knowing the peat surface topography and water level relative to a fixed, independent datum, as it is important in undisturbed peatlands (Roulet 1991).

4.5.6 Increasing effectiveness of the rewetting measures

Although the dams did help to retain water on the harvested site, better design of the site and dams could have improved the effectiveness of these rewetting measures.

Rewetting of the harvested site would have been more uniform if the site was level. The harvested site generally sloped downward ~ 2.7 m in elevation, from the northeast corner to the southern end, with some low lying areas in between. Thus, in 1992 the southern areas were the first to rewet, while the northern half remained dry. In the wet years of 1994 and 1995, depressional areas across the site became flooded. Although it is not advised to presently level the site, due to the established experiments, site surface elevation needs to be taken into consideration for harvesting and restoration plans. Modified harvesting practices should be developed to leave a harvested field level upon the completion of harvesting.

Although our primary dam of compacted peat and roots appeared to be stable, some researchers advise dams to have a section of rigid plastic forced into the remaining peat layer and the ditch edges, with peat sods stacked on either side of the rigid plastic, stabilized by angled wooden piles on the outer edges of the compacted peat sods (Schmilewski 1992). Streefkerk and Zandstra (1994) and Streefkerk et al. (1994) recommend the use of a plastic foil screen, instead of a rigid plastic section, as the foil screen can be folded at the surface of the dam, and thus extendible if needed in response to rising water levels and peat reswelling on the site.

Our primary dam could also have been more effective if the peat surface elevation of the harvested site was taken into account for the dam height. As it was, when water flowed over the primary dam in the spring of 1994 and 1995, I was uncertain whether the flow was excess water, or whether it was necessary water. Streefkerk and Zandstra (1994) advise dam height to be 0.3 m higher than the required water level on the inside of the dam, with an additional 0.2 m of height to compensate for peat subsidence in the dam. The required water level on the inside of the dam is to be determined by the peat surface elevation, avoiding a greater slope in peat elevation than 0.1 m drop/100 m. To avoid possible erosion damage with water flowing over the dam, PVC pipes should be incorporated into the dam at the height of the required water level (Streefkerk and Zandstra 1994). Elevation surveys of the site and dams should be conducted periodically to monitor if any adjustments in dam construction are necessary.

Although the secondary adjustable wooden dams helped to slow down water flow in the western perimeter ditch, and facilitated the rewetting of the eastern half of the site by forcing water up the east/west bay ditches, these internal dams could be improved. Extending the width of the wooden dams further into the ditch edges would prevent the water erosion of the ditch edges, and the detouring of water around the dams. Another solution would be to replace the wooden dams with peat dams. Streefkerk and Douglas (1994) outline methods for constructing internal peat dams. Briefly, cut the peat along the ditch edges with spades, 0.2 m wide, 1 m long, to the base of the ditch. Saving the top 0.3 m, push the rest of the cut peat down to cover the base of the ditch. Continue to cut 0.2 m wide blocks of peat, removing the peat from the ditch edges upslope. With the top blocks set aside as before, pile and compress the remaining peat blocks over the peat sections, and continue until the dam height is no less than 0.2 m above the surface of the peatland. To finish, add the top blocks and firm them in place. These top sods will act as possible seed sources, if any seeds have blown into the harvested site already. Streefkerk and Douglas (1994) advise that these internal dams be constructed in ditches wherever the peat surface slopes more than 0.1 m/100 m.

Thus these improvements to the primary and secondary dams could improve the rewetting measures.

4.6 Conclusions and implications for restoration

With the removal of the acrotelm, water levels in the remaining catotelmic peat in the harvested site were lower and more variable, than water levels in the neighbouring natural peatland. As rewetting is essential for peatland revegetation and eventual restoration, knowledge of the hydrology of a harvested is required.

To ensure revegetation success of a harvested site, the following factors must be heeded.

1/ Increase the water table. Mean annual water level should not be lower than 20 cm below the peat surface in the harvested site.

2/ Stabilize the water table to within natural variation. Annual water level amplitude should not be greater than 40 cm. Keeping water levels close to the peat surface is the aim, to ensure adequate soil moisture for good *Sphagnum* establishment.

3/ Decrease the large water level variation caused by rain storms and droughts.

To accomplish these three points, dams must be well built and monitored for effectiveness. The field should be level to allow for even rewetting. Internal ditches should be left intact to distribute water across the site, and to facilitate rapid water adjustment. Additional ponds may need to be dug to moderate water level fluctuations, however, nutrient status of these need to be considered.

To monitor the success of rewetting on a harvested site, monitoring of water levels and peat elevation in relation to an outside datum is important.

With the success of peatland revegetation, a new acrotelm will develop. The development of a new acrotelm will help to stabilize water level fluctuations, and is another step toward the goal of full restoration.

Table 4-1. Surface bulk density for the harvested and natural sites.

	Harvested peatland Mean ± 1 SD (g/cm3)	Undisturbed peatland Mean ± 1 SD (g/cm3)
1992	0.1341 ± 0.0346 n=22	
1993	0.0947 ± 0.0233 n=40	0.0168 ± 0.0063 n=2
1994	0.0952 ± 0.0277 n=19	0.0467 ± 0.0011 n=2
1995	0.1173 ± 0.0313 n=20	0.0367 ± 0.0158 n=2
Overall Mean	0.1079	0.0334

Table 4-2. Characteristic values for varied peat types*.

	Fibric peat	Mesic peat	Humic peat
Bulk density (g/cm3)	<0.075	<0.075 – >0.195	>0.195
von Post scale of decomposition	Class 1-4	Class 5 or 6	Class 7-10
Hydraulic conductivity (cm/hr)	>6	>6 – <0.1	<0.1

Note: * Information from Agriculture Canada, Expert Committee on Soil (1987).

Table 4-3. Precipitation levels for Entwistle*, Alberta, 1992-1995.

	Precipitation (mm)
1992	413
1993	442 ^
1994	572
1995	585
30 year mean	528.8

Notes: * ~15 km away from the peatland site.

^ Environment Canada was missing October's precipitation values for 1993

Data from Environment Canada (1982b, 1994, and 1997)

Table 4-4. Summary of water level data for the harvested and natural sites.

Harvested peatland

	Range of annual mean water levels (cm)	Range of annual amplitides (cm)	n	% of measured water levels within the natural range	Range of percentages within the natural range
1992	-90 — +20	16 — 40	41	0	—
1993	-91 — -2	10 — 66	137	41	0 — 100
1994	-76 — +59	53 — 111	271	28	0 — 77
1995	-70 — +54	20 — 77	228	37	0 — 89

Natural peatland

	Mean annual water level (cm)	Annual amplitude (cm)	n
1992	-21	33	7
1993	-18	35	21
1994	-6	22	23
1995	-7	24	19

Table 4-5. Water chemistry for the natural area, and flooded areas in the harvested site, means (and ranges).

		n	pH	Conductivity (µS at 20 oC)	TP (mg/L)	TDP (mg/L)	NH4+-N (mg/L)	NO3--N (mg/L)
Natural area,	1994	2	3.7	28.1	0.06	0.04	0.08	0.01
pipe and hollows			(3.7-3.8)	(27.1-29.1)	(0.03-0.10)	(0.02-0.07)	(0.05-0.10)	(0.01)
	1995	2	3.7	0.0	0.08	0.03	0.04	0.01
			(3.7)	(0.0)	(0.06-0.10)	(0.02-0.04)	(0.03-0.06)	(0.01)
Harvested area,	1994	6	5.1	60.7	0.12	0.33	0.07	0.01
wells in flooded			(4.5-5.9)	(46.8-78.3)	(0.09-0.16)	(0.06-0.92)	(0-0.26)	(0.01)
areas	1995	4	5.5	47.9	0.45	0.33	2.44	0.01
			(4.7-6.3)	(26.1-78.8)	(0.14-0.59)	(0.08-0.49)	(0.34-5.16)	(0.01-0.02)
			Na+ (mg/L)	K+ (mg/L)	Ca2+ (mg/L)	Mg2+ (mg/L)	SO42- (mg/L)	Cl- (mg/L)
Natural area,	1994	2	0.71	0.71	2.64	0.94	0.00	0.98
pipe and hollow			(0.62-0.79)	(0.51-0.91)	(2.52-2.75)	(0.83-1.05)	(0.00)	(0.95-1.01)
	1995	2	0.72	0.39	2.23	1.02	3.60	0.59
			(0.67-0.76)	(0.37-0.41)	(2.14-2.32)	(0.93-1.11)	(3.28-3.91)	(0.40-0.77)
Harvested area,	1994	6	4.55	3.31	7.79	3.74	5.59	1.83
wells in flooded			(3.04-8.3)	(1.94-3.94)	(5.95-9.97)	(2.76-5.43)	(2.17-14.61)	(1.16-4.19)
areas	1995	4	8.35	3.11	10.59	3.85	3.45	1.14
			(3.32-22.3)	(2.56-3.4)	(6.94-14.7)	(2.65-5.19)	(1.71-4.73)	(0.92-1.36)

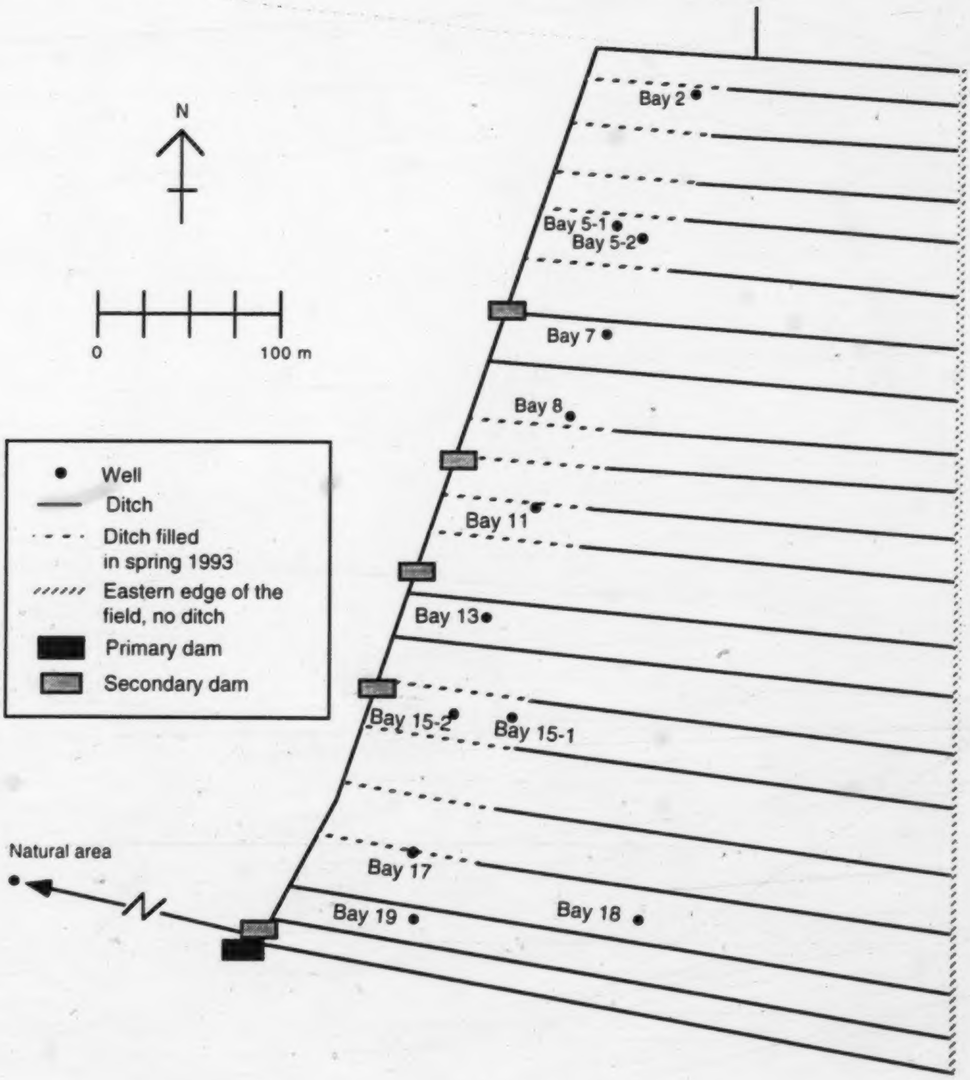
N
0
100 m
● Well
Ditch
Ditch filled in spring 1993
Eastern edge of the field, no ditch
Primary dam
Secondary dam
Bay 2
Bay 5-1
Bay 5-2
Bay 7
Bay 8
Bay 11
Bay 13
Bay 15-2
Bay 15-1
Bay 17
Bay 19
Bay 18
Natural area

Figure 4-1. Well locations

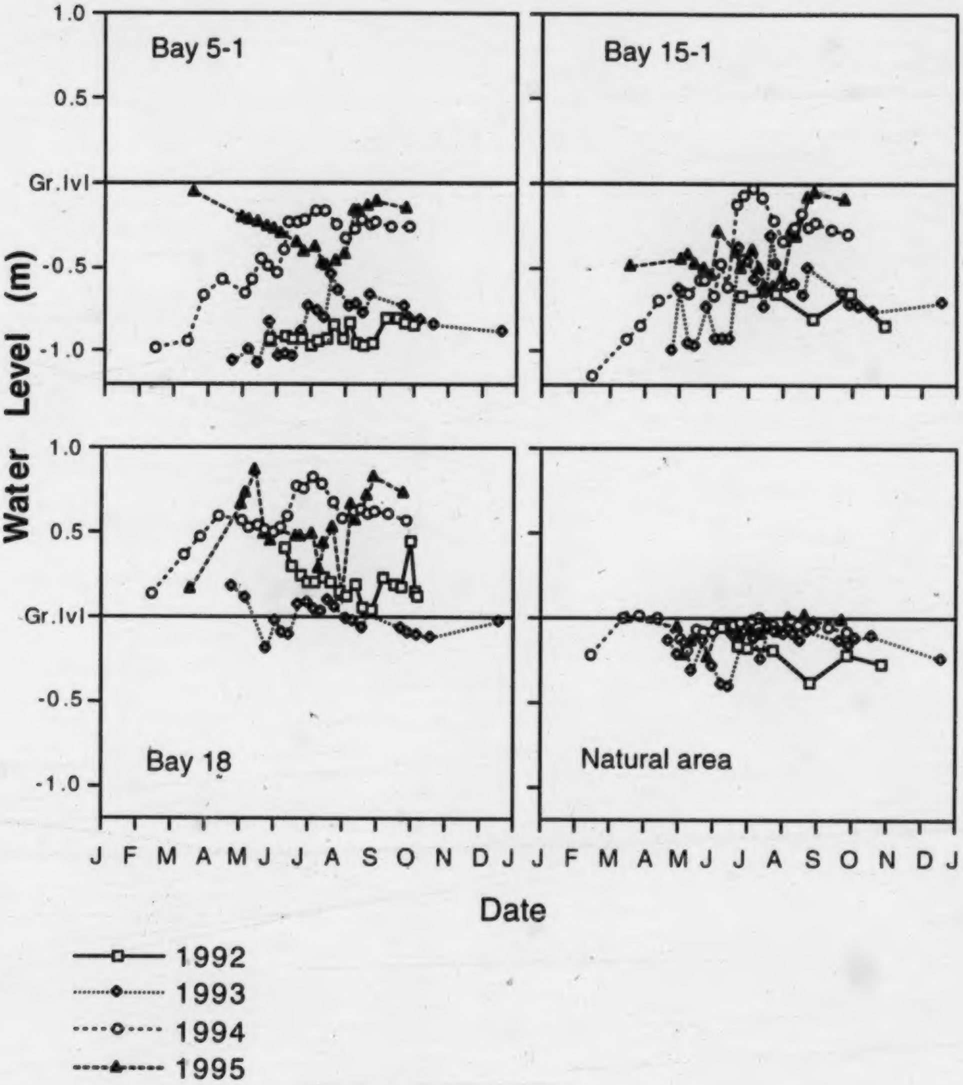

Figure 4-2. Water levels at well locations in the harvested and the natural areas, 1992-1995.

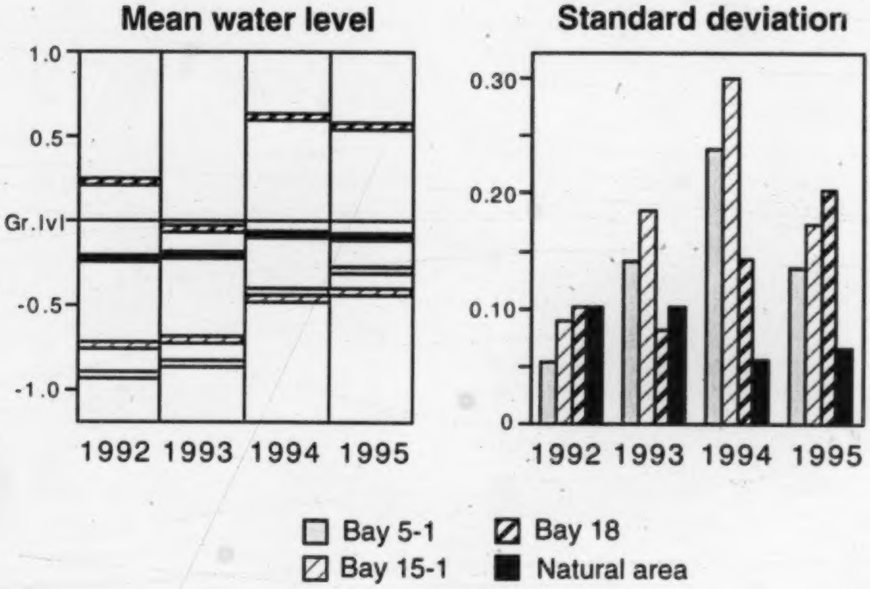

Figure 4-3. Annual mean water level and 1 standard deviation at well locations in the harvested and the natural areas, 1992-1995.

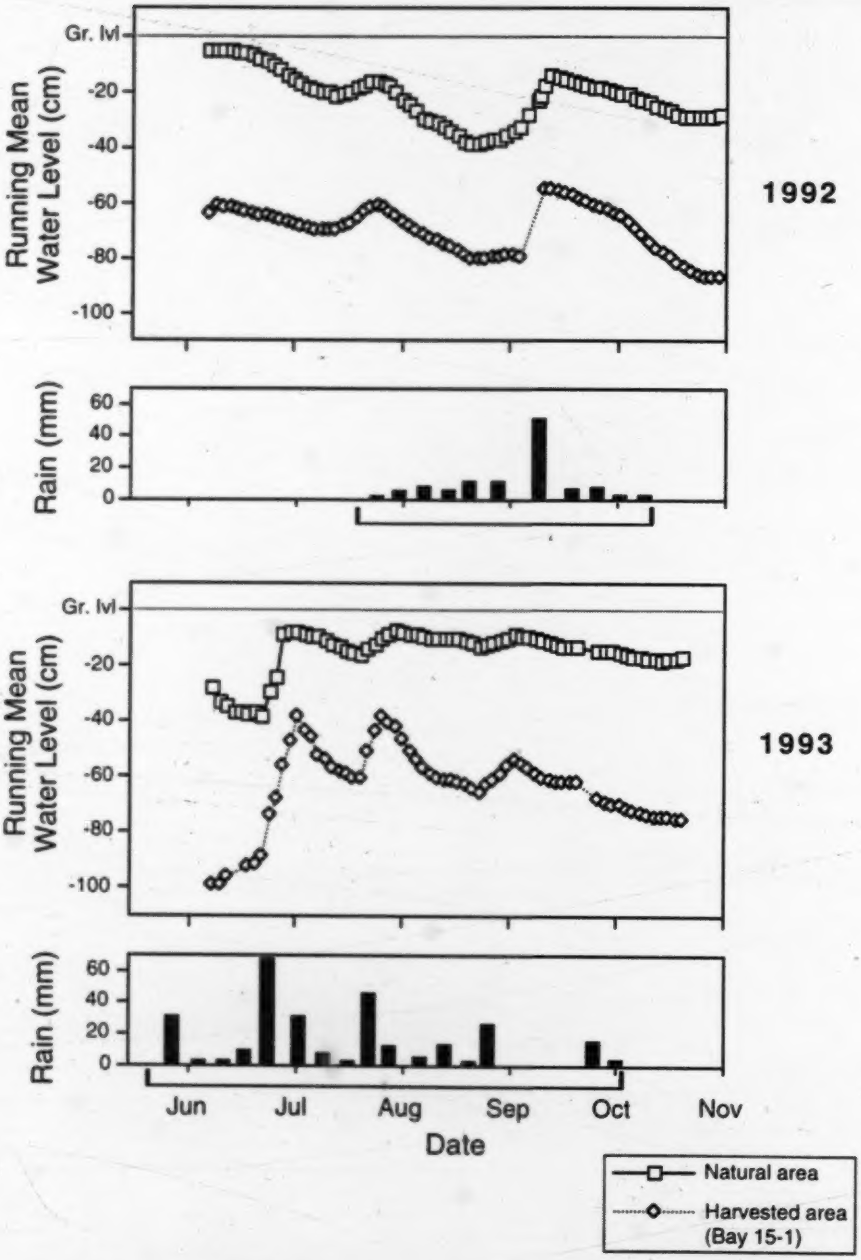

Figure 4-4. Running mean water level and rainfall, 1992-1993. Each point represents a running mean of ten days with measurements every two days. Underline indicates the time over which rain levels were measured.

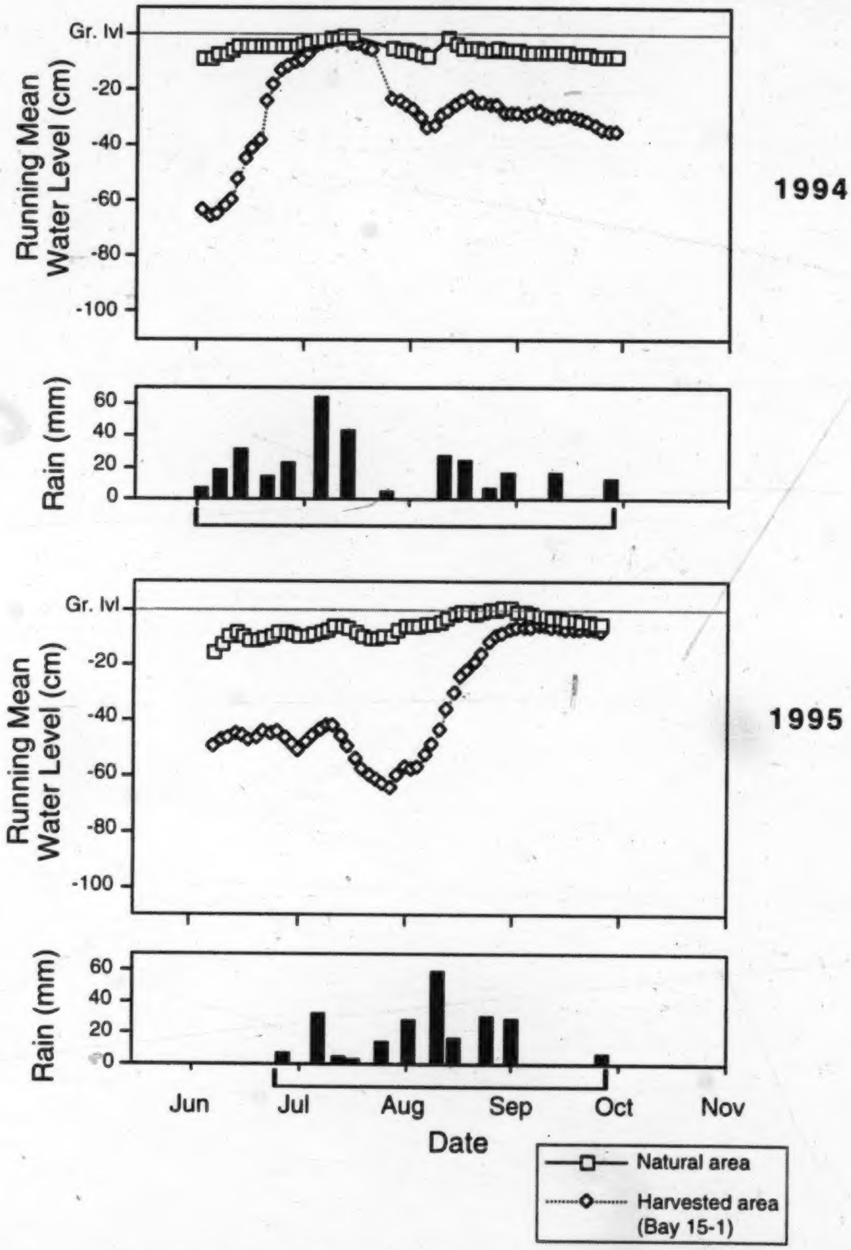

Figure 4-5. Running mean water level and rainfall, 1994-1995. Each point represents a running mean of ten days with measurements every two days. Underline indicates the time over which rain levels were measured.

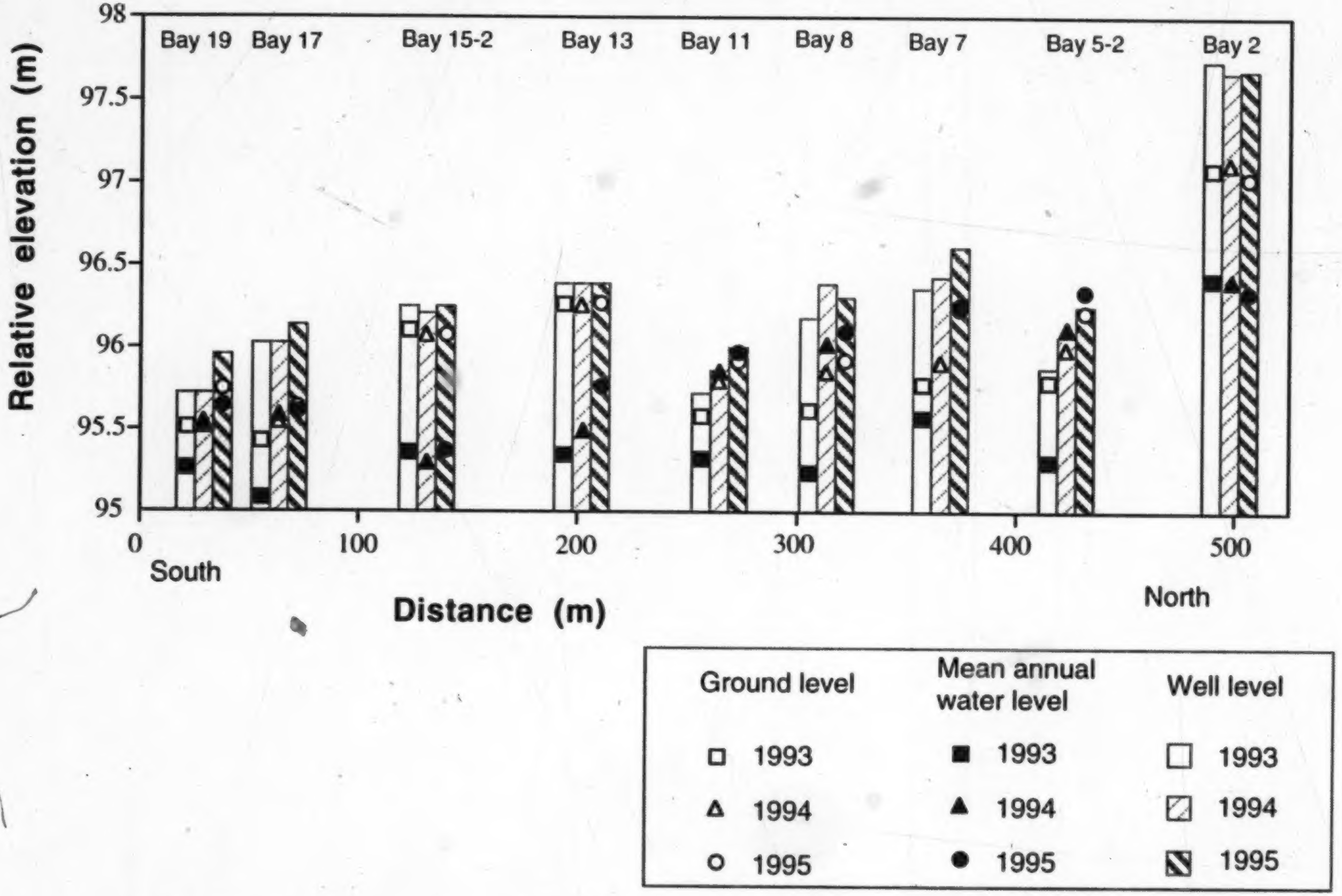

Figure 4-6. Ground, well, and mean annual water levels across the harvested site, 1993-1995.

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Chapter 5

Restoration of a harvested peatland: Top spit experiments to enhance revegetation

5.1 Introduction

Peatlands are found throughout the world, but are most common in northern countries. Peatlands develop in certain areas due to topography, hydrogeology, and such climatic variables as moisture and temperature. Canada has an estimated 170 million hectares of peatland, more than any other country (Gorham 1990). Although peat harvesting has been extensive in Europe, it is a relatively new industry in Canada. The earliest horticultural peat harvesting companies started in the 1930s and 40s, with the majority starting in the 1960s. Canada has about 75 peat harvesting operations, selling about 850 000 metric tonnes of peat moss annually (Keys 1992).

Peat harvesting impacts a peatland's characteristics and functions with such harvesting procedures as drainage, vegetation removal, peat extraction, and peat compaction by machinery and decomposition. Harvested sites have restoration complications, including low and variable water levels, peat oxidation, wind and water erosion, surface crusting (Famous et al. 1989, Nilsson et al. 1990), high peat surface temperatures (Grosvernier et al. 1995), and removal of the seed bank (Salonen 1987). Vacuum harvesting, the most prevalent harvesting method in Canada, requires large expanses of peatland to be open for harvesting at one time. This hinders the recolonization of peatland plants due to distance for seed sources (Nilsson et al. 1990). Diaspores of vascular plants and bryophytes that reach a harvested site often cannot germinate and survive the harsh conditions (Salonen 1987, Poschlod 1995). These problems inhibit the recolonization of the harvested fields by peatland plants, and due to the dryness and other harsh conditions natural revegetation is slow to take place on abandoned vacuum harvested sites (Nilsson et al. 1990). Techniques need to be developed to accelerate the revegetation of these sites in order to begin the restoration process to become functioning peatland ecosystems once again.

Sphagnum species play an important role in the formation, development, and functioning of peatlands, and thus are a keystone species in the restoration of damaged peatlands. *Sphagnum* species have a large water holding capacity, and aid in the rise and stability of groundwater levels. The process of oligotrophication is assisted as Sphagnum acidify their surroundings, directing succession from minerotrophic fens to ombrotrophic bogs (Clymo 1963). By spores, vegetative reproduction (Cronberg 1993), or almost any cut segment of the plant (Sobotka 1976, Poschlod and Pfadenhauer 1989, Rochefort et al. 1995a), *Sphagnum* can recolonize rewetted peat fields.

To examine different revegetation techniques for restoration, a harvested site was selected in central Alberta. Harvesting had recently been completed and ditches were blocked to aid rewetting of the site. Earlier experiments by the author (not discussed in this dissertation) focused on single species of mosses and vascular plants, followed by chosen planted mixtures. As these experiments used vegetative material all hand collected and hand planted, and harvested sites are quite large in size, more mechanized, large-scale restoration methods are desired. Thus the application of top spit is here investigated.

Top spit is the living vegetative surface layer of a peatland, and it can provide a valuable source of seeds, spores, and vegetative propagules for the harvested site (Poschlod 1995), a good mixture of both *Sphagnum* and vascular plant species. Clymo and Duckett (1986) found that *Sphagnum* spores, and portions of *Sphagnum* from brown and seemingly dead stems can regenerate, up to a depth of 30 cm. Campeau and Rochefort (1996) stated that the top 10 cm of *Sphagnum* gave the best regeneration rates. Top spit also provides microbial species that help in plant re-establishment (Roderfeld 1993).

In Germany, it has been legislated that the top 30 cm is to be removed from the peatland before harvesting, stored during harvesting, and reapplied to the site once harvesting is complete (Niedersächsisches Landesverwaltungsamt - Fachbehörde für Naturschutz 1990, Schmatzler 1993). Another top spit application method is to remove the surface vegetation from a section of peatland that is being opened for harvesting with application to another field where harvesting is completed (Schmilewski 1992). Other researchers have examined the use of natural areas as a source of top spit material, using only the top 10-15 cm, noting good recovery rates at the source sites (Campeau and Rochefort 1996, Quinty and Rochefort 1997).

The purpose of this chapter is to investigate the use of top spit as a restoration approach in western Canadian boreal peatlands. New top spit, taken from an area newly opened for harvest, was mechanically chopped and spread onto the harvested site. During the first year, timing of application and thickness of bog top spit was examined. The following questions were asked:

1/ When is the best time to spread top spit on the site?

2/ How thick should the top spit application be? Does more top spit result in more revegetation?

In the first year of the experiment, initial plant growth was slow, but increased by the end of the growing season. Sedges dominated the plots, with little *Sphagnum* moss growth. A second application of top spit was thought to possibly promote more moss growth, with the already established sedges acting as companion plants and a growing lattice for the moss. Thus in the second year, the following questions were examined:

3/ Would a two-step top spit application process increase levels of revegetation? Would this two step process specifically increase moss growth?

Additionally in the second year, experiments were set up to compare top spit of different peatland types, bog and poor fen top spit. Although the harvested site formerly was a bog and eventually restoration to a bog was desired, the chemistry is currently more similar to a fen (see chapters 2 and 3). Also, as conditions can be harsh for vegetation establishment on a harvested peatland, a protective mulch was added to a number of the bog and fen top spit plots. Straw was chosen as a cheap and readily available mulch medium. With regards to this set of experiments the following questions were studied:

4/ Does bog or poor fen top spit revegetate more successfully on the site?

5/ Does a protective straw covering over the applied top spit increase vegetation cover?

In the course of these top spit experiments, measurements of the percent cover of the different plant species which grew were recorded. Species diversity and abundance were analyzed for the various treatments to answer these questions:

6/ Which treatments had the highest species diversity and the greatest vegetation cover? Did high species diversity coincide with high vegetation cover?

7/ What plants grew on the top spit plots? For example, how did sedge growth compare to moss growth? Did plants other than peatland plants grow on the top spit plots?

As these top spit experiments were limited to a single harvested site (there were no other local harvested sites available for restoration study), some researchers may have concerns about pseudoreplication. Even though samples were replicated, the treatments were not truly replicated, and the treatments could be confounded by undesirable effects (Hurlbert 1984). Although site limitations constrained these experiments, other top spit experiments by Line Rochefort's research group provide comparative results, and help to overcome these limitations.

5.2 Site description

The Seba Beach peatland is located about 130 km west of Edmonton (53°33'N, 114°44'W; Fig. 1). This peatland is classified as a Continental Mid-Boreal peatland (NWWG 1986). The area has a mean annual temperature of 2.4 °C, with a mean January temperature of -15 °C and mean July temperature of 16 °C. Average annual precipitation for the area is 528.8 mm, with a quarter of the total precipitation falling as snow.

Originally this peatland was covered by bog and poor fen vegetation dominated by *Picea mariana*, *Sphagnum fuscum*, *S. magellanicum*, *S. angustifolium*, and scattered *Larix laricina*. This site was first opened in 1975 to harvesting by dredging. In 1980, Fisons Horticulture Inc., now Sun Gro Horticulture Canada Ltd., acquired the site and leveled, drained, and then vacuum harvested the area. The restoration site is approximately 16 hectares in area, 0.02% of the area presently being harvested by Sun Gro. Surface height of the peat is highest in the northeastern corner sloping to the southwest corner, with drainage southwestward. Peat depth ranges from 0.73 m at the northern end, deepening at the southern end to over 4 m.

In order to raise the water level, a dam was constructed in the southwest corner in the fall of 1991, when peat harvesting ceased. In early 1992, the lower areas of the southern end of the field were flooded, with the northern end of the site staying relatively dry. For the top spit experiments, starting in 1994, a slightly lower area was chosen on the site with the hopes that moisture levels would be sufficient for good vegetation growth (Figure 5-1). The harvesting bays (the area between two ditches) were bare of vegetation, with some willows and grasses in the ditches. The heavy snowfall in the winter of 1993/94 (Table 5-1) helped to rewet the experimental area, so that the peat became saturated throughout, with some periodic flooding.

Due to the removal of the bog peat with harvesting, the chemistry had been altered on the site. Peat and water chemistry was now more similar to a poor to moderate-rich fen, as described in chapters 2 and 3.

5.3 Methods

5.3.1 Timing and thickness of top spit additions

To investigate the questions of timing and thickness of top spit application, top spit was gathered and spread in the winter, spring, and summer of 1994, with two thickness levels of 1-2 cm and 2-4 cm. The experimental area was placed in a slight depression in the field, across several harvested bays. Although the harvested field was still in the process of resaturating, and many areas were still dry and considered unsuitable for vegetation growth, this area was chosen as a place where moisture levels would potentially be sufficient for good plant growth.

In December 1993, bog surface vegetation was excavated by bulldozer from an area which was presently being opened for peat harvesting[1]. The surface layer, to a depth of approximately 20 cm, was scraped from the peatland surface, then trucked to the restoration site. In March 1994, a Heavy Duty Industrial tub grinder (HD-12) chopped the top spit material. Vegetation pieces were approximately 0.5 - 1.0 cm in length. The chopped material was spread on a snow and ice covered bay with a clean manure spreader. Within the winter treatment, the material was raked to either one of two thickness levels; 1-2 or 2-4 cm.

For the application of the top spit material, the use of a hydroseeder, instead of a manure spreader, was investigated. A hydroseeder would necessitate the material to be chopped quite finely to pass through the sprayer nozzle, and costs were higher than a local manure spreader.

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[1] The excavation time was chosen by the Sun Gro staff, with regards to the availability of machinery and men. Regrettably I was only notified after the top spit was gathered and brought to the restoration site. No prior identification of the bog vegetation to species and percent cover was done. In addition, the top spit material was piled for 2 $^1/_2$ months before application on the field.

In May 1994, once the snow had melted but the ground was still frozen enough to support heavy machinery, the manure spreader distributed top spit material on an adjacent bay, for the spring treatments. The material was raked over the bare peat surface to a thickness of 1-2 or 2-4 cm.

For each of the two top spit thickness levels, eight experimental plots were set up within each treatment. Plot size was 5X5 m^2, with 1 m spacing between plots. A boardwalk was built between the plots for easier access and less impact. Four control plots, with no top spit additions, were set up on both bays.

Site and industry constraints limited the random placement of the treatment plots. Treatments could not be randomly interspersed throughout the experimental area, due to limitations with machinery. A manure spreader has a limited preciseness in its spreading capability. Thus, control plots were placed at either end of the bays to prevent possible contamination of top spit from the spreader (Figure 5-1). Different timing treatment plots were not randomly placed on the harvesting bays, as the bays were not wide enough to allow a spreader to be able to drive around any previously established plots. Thus the winter and spring treatments were set up on two separate bays. In these ways the experimental design was constrained by site and industry limitations.

Due to the slow start of growth of the winter and spring plots, it was decided that additional plots should be set up. In August 1994, additional bog top spit was brought to the site, chopped by a rototiller and distributed by wheelbarrows and raking. Summer treatment plots were slightly smaller due to field constraints, 5X3 m^2 with $^1/_2$ m spacing. Top spit thickness was set at one level, 1-2 cm thick.

In addition to the use of top spit alone, it was planned to have such nurse plants added as trees and native annual grasses, to some of the top spit plots. It was thought that these companion plants could possibly ameliorate the plots by such things as reducing wind erosion and increasing shade and humidity, thereby indirectly aiding in the establishment of the vegetation from the top spit. In July 1994, tree planting of young *Picea mariana* and *Larix sibirica* was started, but abandoned when flooded conditions in some of the plots caused the recently planted trees to float away. The flooding also prevented the sowing of native grass. The planted trees subsequently died due to the wet conditions.

In the fall of 1994, the top spit plots had some sedge growth with little moss growth. With the thought that the established plants could act as companion plants, the question of whether a second application of top spit would increase vegetation cover, with a specific focus on moss growth was examined.

In May 1995, bog top spit was brought to the site, chopped by a rototiller, brought to the plots by wheelbarrows, and spread by shovels to half of each of the spring treatment plots (Figure 5-1). The spring plots were chosen since the winter treatment plots were not easily accessible by wheelbarrow due to flooding at the time, and the summer plots had less sedge growth than the other two timing treatments.

For ease of references, the top spit timing and thickness treatments will have the following designations.

Winter 1 for the winter treatment with the thinner layer of top spit (1-2 cm).

Winter 2 for the winter treatment with the thicker layer of top spit (2-4 cm).

Spring 1 for the spring treatment with the thinner layer of top spit (1-2 cm).

Spring 2 for the spring treatment with the thicker layer of top spit (2-4 cm).

Summer 1 for the summer treatment with the thinner layer of top spit (1-2 cm).

Control plots had no top spit applications.

Second application 1 for the second application of top spit treatment on the spring 1 plots.

Second application 2 for the second application of top spit treatment on the spring 2 plots.

Second application controls had a single layer top spit applied control plots in the spring area.

5.3.2 Type of top spit material and straw covering

To answer the question of which peatland type of top spit would revegetate more successfully on the site, both bog and poor fen top spit was transported to the site, chopped by a rototiller to approximately 1 cm lengths, and distributed by wheelbarrows and raking, in May 1995. One top spit thickness level of 1-2 cm was used. Experimental plots were 5X5 m^2 in size, with 1 m spacing. Bog and fen treatments had six plots each. Half of the plots received a covering of straw at a rate of 1 bale per 50 m^2, similar distribution as Rochefort et al. (1995b). The *Avena sativa* bales were approximately 1 m X 0.5 m X 0.5 m in size. Garden netting was placed over the straw and pegged down with sticks found in the vicinity to keep the straw from blowing away. Four control plots, with no top spit application, were set up. A boardwalk was built in between the plots for easier access and less impact on the site (Figure 5-1).

5.3.3 Measurements

Measurements of vegetation cover were recorded initially and then periodically during the growing season until the fall of 1995. Percent cover was estimated visually by the author for each plant species on three randomly placed 50 X 50 cm^2 quadrats for each plot and then averaged to determine a plot mean. Species richness was measured by the number of plant species recorded in each quadrat, and then averaged to determine a plot mean.

5.3.4 Statistical analyses

In order to determine the revegetation success of the different treatments, both vegetation cover and number of plant species were examined. Vegetation cover gave an indication of the level of vegetation establishment on the plots. Although the top spit treatments had good plant growth, much bare ground was still available for colonization after the experimental runs of one or two years. These cover measurements could change through time. For example, a species with low cover value and slow recruitment rate could dominate given more time (see Li and Vitt 1994, 1995). A treatment with low vegetation cover and high species diversity could more successfully establish in time. Therefore, treatment success was also examined with regards to the number of species present.

For statistical analysis, the final number of species and vegetation cover measurements from September, 1995 were grouped into vegetation categories. The following vegetation categories were chosen: sedges, rushes and cattails[2]; mosses; bog shrubs; fen shrubs; herbs; grasses; and total vegetation. The measurements were also regrouped to examine species characteristically found in disturbed areas and in nondisturbed areas, and to compare peatland plant species with nonpeatland plant species (Tables 5-2 through 5-5). Data were not normally distributed and variances were not homogenous. Spread versus level graphs and power of transformation values were generated, and transformations to normalize the data were attempted. Transformations could not fully normalize the data and homogenize the variances. Thus, nonparametric tests were used, with an alpha value consistently set at 0.05.

Since the top spit timing and thickness experiments were laid out over two harvested bays, separated by a ditch, statistical analyses were necessary to determine whether environmental conditions on the two bays were the same and whether those conditions were the same as those on the rest of the field. Mann-Whitney U-Wilcoxon rank sum W tests were used to compare the control plots on the two bays for vegetation cover and species diversity. In addition, peat chemistry of the two bays were compared to the harvested field peat chemistry (See Chapter 3, section 3.3.2 for peat chemistry methods).[3]

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[2] Few rushes and cattails were found on the experimental plots, and thus they were grouped together with sedge species, as these plants have similar growth form and habitats.

Then to determine that the planted trees, which had since died, did not significantly affect vegetation cover, Mann-Whitney U-Wilcoxon rank sum W tests compared the treed and nontreed plots in the winter, spring and second application treatments. Kruskal-Wallis 1-way analysis of variance tests were followed by Tukey-type multiple comparison tests for the timing, thickness and top spit type experiments. Wilcoxon matched-pairs signed ranks tests compared the vegetation cover on the spring plots with the second application plots. The computer package SPSS was used for all these statistical tests (SPSS 1995), with the exception of the Tukey Type Multiple Comparisons tests which were calculated by the author.

5.4 Results

5.4.1 Timing and top spit thickness

5.4.1.1 Harvested Bays 7 and 8 compared

To verify that the two harvested bays had comparable growing conditions, the control plots on the two bays were compared. There were no significant differences in vegetation cover or species diversity of any of the vegetation groups. In addition, peat chemistry comparisons for Bays 7 and 8 showed only a few values outside ±1.5 standard deviation range for the harvested site for 1994 and 1995 (Table 5-6). Bay 8 had a peat sample that was higher than the 1.5 standard deviation range for the harvested site in 1994 for K (1606 mg/kg) and Mg (2306 mg/kg), and in 1995 for K (936 mg/kg). All other chemical components were within the 1.5 standard deviation range (Table 5-6, for peat chemistry of the whole field see chapter 3, Table 3-2). As the peat chemistry of the two bays was comparable to each other and the rest of the harvested site, these results indicated that growing conditions for the treatment plots were similar on both harvested bays, and would not have affected one treatment more than another.

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[3] No water level wells were located by the top spit plots, so water level comparisons could not be made.

5.4.1.2 Nurse tree seedlings affect on top spit growth

For the top spit timing and thickness experiments, the effect of the nurse trees was first examined. The planted spruce and larch seedlings, which were to act as companion plants on the winter and spring treatments, did not survive in the wet and sometimes flooded conditions. Both vegetation cover and number of plant species were compared, to analyze whether the trees significantly affected the plots. For vegetation cover, the only significant differences were found in spring 1 herbs and second application 1 bog shrubs. Although in these treatments the treed plots had slightly higher cover values than the nontreed plots, the maximum treed plot cover values were only 1 or less than 1% for the previously mentioned vegetation categories. For the number of plant species, the second application 1 treatment had significant differences in the number of grass species. The nontreed plots had a slightly higher number of grass species than the treed plots. But as with the low cover values, the number of grass species in this comparison was also very low. As these cover values and number of species were very low, the treed and nontreed plots were grouped together in their respective treatments for further statistical analyses.

5.4.1.3 Effect of top spit thickness on the revegetation of top spit

To address the question of top spit thickness, the two thickness levels were compared in the winter and spring treatments. Generally, a thinner layer of top spit, 1-2 cm, had higher vegetation cover values and number of species than the thicker 2-4 cm layer, in the fall of 1995 (Figures 5-2a and b). These differences between the thicker and thinner layer were not significant except for two comparisons. The percent cover for vegetation groups peatland plants and plants typically found in nondisturbed areas was significantly higher in the spring 1 than the spring 2 treatment (Figures 5-3a and b). Thus, the comparisons of the two thicknesses of top spit showed that more top spit does not necessarily result in more revegetation, but rather less top spit is needed to cover an area for revegetation.

5.4.1.4 Vegetation cover results and timing of top spit application

To investigate the question of the most successful time to apply top spit onto the harvested site the winter, spring and summer treatments were compared with regards to vegetation cover and number of plant species. Vegetation cover comparisons will be addressed first.

When examining mean percent vegetation cover for the timing comparisons, spring 1 was the most successful treatment with significantly higher cover values for total vegetation, sedges, rushes and cattails, and moss, and low cover for the weedy groups of herbs and grasses (Figure 5-3a). Sedges were the dominant plants on all of the timing plots, as shown by the close correspondence of the category sedges, rushes and cattails to the total vegetation cover (Figure 5-2a). Spring 1 was dominated by *Carex aenea* and *Scirpus microcarpus*, with low values for *Carex interior* and *C. curta* (vegetation list, Table 5-7). The winter plots were dominated by *Scirpus microcarpus*, and the summer plots had the highest levels of *Carex interior*. Sedges on the control plots were mostly *Scirpus microcarpus* and *Carex aenea*. Cattails and rushes had low cover on the plots.

Moss cover values were highest in the spring and summer treatments (Figure 5-2a), although the percent cover was still low in these plots, ranging from 0-7%. The main mosses were *Aulacomnium palustre*, *Sphagnum* species, *Polia nutans*, and *Polytrichum strictum*. In the spring plots *Aulacomnium palustre* was most prevalent, producing many stalks with asexual diaspores and sometimes forming large clumps. *Sphagnum* tended to be found in small scattered clumps. *Sphagnum angustifolium* was the most common *Sphagnum* species, with smaller amounts of *S. magellanicum* and *S. fuscum*. *Polia nutans* also formed smaller clumps, while *Polytrichum* was scattered, occasionally forming larger clumps. Other mosses were more infrequent. In the summer plots, *Polytrichum strictum* was most common, followed by *Sphagnum* species, *Polia nutans*, and *Aulacomnium palustre*. The control and winter treatments had very little moss cover.

Very little growth was observed in the two categories of bog shrubs, and fen shrubs (Figure 5-2a), with the summer treatment being the only single application treatment to have any bog shrubs (Table 5-7).

The weedy groups of herbs and grasses had the lowest mean cover values on the spring plots (Figure 5-2a). *Bidens cernua* was the most common herb, found in all the treatments, and accounted for most of the herb cover. The other herbs were much more infrequent. Grass cover was low over all on the plots, with *Agrostis scabra* being the most frequent grass species. Although the spring treatment had low cover values for these two weedy groups, they did have a high percentage of their total vegetation cover composed of plant species commonly found in disturbed areas (Figure 5-4).

These results indicate that the spring 1 treatment was the most successful timing treatment with the highest vegetation cover values, and thus early spring appears to be the best time for top spit application.

5.4.1.5 Species diversity results and timing of top spit application

Species diversity in the different treatments showed that the highest number of species did not correspond to the highest vegetation cover on the top spit plots. As discussed in the previous section, spring 1 treatment had the highest vegetation cover of the various timing treatments, yet it did not have the greatest species richness. Instead the summer treatment had the highest number of plant species (Figure 5-2b and Table 5-7), with a significantly lower amount of vegetation cover than spring 1 (Figures 5-2a and 5-3a). The summer treatment also had the lowest percentage of species characteristically found in disturbed areas (referred to as disturbed area species), and the highest percentage of peatland plant species (Figure 5-4). In contrast, the spring 1 treatment had a low number of disturbed area species with high vegetation cover, and a high number of peatland plants with low vegetation cover. Even with these differences, the spring 1 treatment was often not significantly different from the summer treatment with regards to the number of species vegetation groupings, except for the group bog shrubs (Figures 5-3a and b).

These results indicate that the summer treatment had highest proportion of peatland plants and the highest species richness, although the spring 1 treatment was often not significantly different from the summer treatment. Thus factors influencing the summer treatment enhanced species diversity and peatland plant establishment, although vegetation cover was low.

5.4.1.6 Two-step top spit application results

A second application of top spit was applied to see whether a two-step process would increase revegetation cover, specifically moss growth under the previously established sedges in the spring plots. The second application plots had similar revegetation results compared to the corresponding spring plots, but often with higher vegetation cover values and number of species (Figure 5-5). The second application treatments did significantly increase moss and bog shrub growth in a number of the treatment comparisons. Mean percent vegetation cover had significant differences for the vegetation groups moss and bog shrubs in the thicker layer (2-4 cm), as well as significant increases in the percent cover of nondisturbed area plants and peatland plants in both top spit thicknesses (Table 5-8). For species diversity, the second application treatment had significantly higher numbers for moss, total vegetation, nondisturbed area and peatland plant species for both top spit thickness, and significantly higher numbers for bog shrubs in the thicker layer (Table 5-8). The spring plots had no bog shrubs, while the second application plots had small amounts of a number of bog species (Table 5-7). The second application treatments decreased the proportion of disturbed area species with regards to the percent cover and number of species, compared to the spring treatments. The second application treatments also increased the proportion of peatland species from the total vegetation cover and number of species (Figure 5-6). No significant differences were found between the spring and second application controls, although low n values may have affected these results.

Thus, the second application treatment did aid revegetation success for some vegetation categories. But was this treatment more successful than the single application treatment, summer 1? Examining only the thinner layer for simplicity, second application 1 was compared to the summer treatment. The second application 1 treatment was usually significantly higher in vegetation cover and usually lower in number of species compared to the summer treatment (Table 5-8). Thus, the second application treatment was more successful in revegetation cover, but not as successful in the number of species compared to the summer treatment.

These results show that an a second application of top spit will increase vegetation cover and species diversity on areas that are revegetating poorly, but will not significantly aid areas which already have a high vegetation cover and/or species richness.

5.4.2 Top spit type and straw covering

The second set of top spit experiments compared top spit type, with and without a straw covering. Top spit from a bog and poor fen were assessed. These experimental results were from only one growing season, and with the low n values only preliminary conclusions can be made. No significant differences were observed between the top spit treatments with and without the straw covering. In other words, a straw covering did not significantly aid revegetation. Often there was no significant difference between the bog and fen treatments (Figure 5-7).

The top spit treatments, while not always statistically different from the control treatment, did appear to improve revegetation levels. The control treatment always had the lowest mean rank in the significance tests (Figure 5-7), and the lowest number of plant species (Table 5-9). The control plots had no mosses, while the bog and fen treatments had a number of peatland mosses present. (Table 5-9, Figures 5-8a and b). Moss cover ranged from 0-3% on the top spit plots. The control plots also did not have any bog shrubs, while the treatment plots had some bog species, although the cover was low. The control treatment also had the highest proportion of total vegetation composed of disturbed area species and their cover, with the lowest proportion of peatland species and peatland plant cover (Figure 5-9).

Fen shrub cover and number of species were low in all the treatments, with no significant differences among the treatments. As in the top spit timing experiments, *Bidens cernua* was the dominant herb, while *Agrostis scabra* was generally the most common grass species. Both straw treatments had the added weeds of oats and corn spurry (*Avena sativa* and *Spergularia arvensis*) present, presumably seeded from the straw (Table 5-9).

Although the fen and bog top spit treatments had many similarities there were some differences. The fen treatments usually had a higher mean rank for percent cover and number of species than the bog treatments (Figure 5-7). The fen treatments had a higher proportion of their total vegetation cover consisting of sedges, compared to the bog top spit treatments (Figure 5-8a). The fen treatments were dominated by *Carex curta*, while the bog plots had more *Scirpus microcarpus* than *Carex curta*. The fen treatments had approximately double the mean *Sphagnum* cover than the bog plots. The bog treatments had a higher proportion of weedy herb and grass cover, while the fen plots had a much lower vegetation cover for these groups (Figure 5-8a).

These results suggest that fen top spit will more successfully revegetate this site. On this site the more fen-like chemical conditions (see Chapters 2 and 3) were presumably favorable for the fen top spit.

5.5 Discussion

Comparisons of the two thicknesses of top spit, 1-2 cm and 2-4 cm, showed that more top spit does not necessarily result in more revegetation. Quinty and Rochefort (1997) have conducted top spit experiments with varied top spit thickness as well. Top spit thickness was varied from "scant" (material covering less than 50% of the ground), "thin" (more than 50% of the ground covered), to "thick" (100% of the ground covered by a layer more than 1 cm thick). Without a mulch, such as straw, they found that the individual numbers of vascular plants, mosses and *Sphagnum* mosses increased with top spit extent and thickness. Yet with a mulch, they recorded higher numbers of plants with the "thin" layer of top spit. They suggested that with thicker applications of top spit the surface material may not be in good contact with the ground and soil moisture, and the vegetative propagules on the bottom may be hindered by burial. Thus combining Quinty and Rochefort's top spit without mulch results with our higher revegetation levels on the thinner application, a thickness of 1-2 cm of top spit appears to be an optimal thickness for revegetation.

Differences were found in the timing treatments, with spring 1 having the highest vegetation cover and summer 1 having the highest species richness. Some speculations on the reasons for the differences in the timing results may be made. The cool, moist conditions at the start of the spring plots may have served to help the establishment of vegetative propagules. Perhaps more plant species would have survived if the top spit had less lag time between collection and application on the field (a period of 5 months in total). The winter treatments may have had lower levels of vegetation due to the effect of freezing and thawing cycles in early spring on the exposed layers of top spit. The summer treatment had hotter weather during the application time than the other two timing treatments, which may have allowed more drying of the top spit material during the critical establishment stage. Yet the summer treatment had less lag time between collection and application of the top spit than the other treatments (collected 1 day, spread the next), which may have increased the survival of more plant species, specifically peatland plants. Lower levels of sedge cover in the summer treatment may have been a result of fewer viable seeds in the top spit due to the time of collection during the year. Also, the summer treatment was started three months later than the spring plots, and perhaps with longer study period, vegetation cover of the summer treatment would have increased to the spring treatment levels. These speculations also show the difficulty in teasing out the complicating effects of timing of top spit application, and lag time between collection and application of the top spit. Further experiments could investigate these factors more fully.

In these top spit experiments, plant establishment on the bare harvested peat surface is the most critical step of the revegetation process. Favorable conditions for establishing individuals may be different than for the growth of mature plants. Li and Vitt (1994, 1995) examined the establishment requirements of nutrients and moisture levels for a number of peatland mosses. They found that *Aulacomnium palustre* had a wide tolerance range of moisture and nutrients levels, quickly colonizing the bare peat by means of asexual diaspores. Over time, *A. palustre* was restricted by competition from other mosses. *Polytrichum strictum* also had a wide tolerance range for establishment, with a slower recruitment rate than *A. palustre*, yet it could better compete than *A. palustre*. *Sphagnum angustifolium* was the *Sphagnum* with the best establishment rate among the species that they tested. *Sphagnum* species had a more limited tolerance range for establishment with a slow recruitment rate, but they could out compete *Polytrichum strictum* in the wetter areas, while the reverse was true in drier areas.

Moss establishment results in our top spit experiments concur with some of Li and Vitt's findings. *A. palustre* was common, with most stems having gemmae at their tips, allowing for quick recruitment. *Polytrichum strictum* was also common, but grew more slowly than *A. palustre*. *Sphagnum angustifolium* was the most common regenerating *Sphagnum* species. As there is still bare ground in the plots (treatment mean cover ranging from 65-95%), competition of moss species is thought to be low, but should play a larger role with time.

Many species typically found in disturbed areas were observed on the experimental plots. *Carex aenea*, *Bidens cernua*, *Rumex crispus*, *Epilobium angustifolium*, *Trifolium* spp., *Taraxacum officinale*, *Agrostis scabra*, *Ceratodon purpureus*, and *Leptobryum pyriforme* are all plants found on disturbed soils and waste ground. No significant differences were found in the percent cover and number of disturbed area species of the timing treatments compared to the control. Thus these plants appear to establish in a uniform pattern across the field, regardless of the different treatments. It is unknown whether these disturbed area species will hinder or help peatland plant establishment over time. These plants may be good pioneer species, helping to moderate field conditions by reducing wind erosion, evaporation, and increasing shade, and may die out as peatland plants establish and out compete the pioneers. Or these plants may become firmly established and peatland plants may have a difficult time displacing them. As it is unknown whether these plants will help or hinder peatland plant establishment, it is recommended to initiate revegetation measures as soon as areas are sufficiently wet. Thus any establishing disturbed area species can shelter the introduced peatland plants, but would not have a chance to cover the peat surface. With wet peat conditions, and further acidification and oligotrophication of the site by *Sphagnum* species, disturbed area species would be displaced, and more steps toward restoration of the site would be made.

Other researchers have found that a straw covering was beneficial to peatland restoration using top spit material. Rochefort et al. (1995b) and Quinty and Rochefort (1997) found that a straw covering resulted in larger, healthier *Sphagnum* plants. Straw is suggested to reduce wind erosion and solar drying, increase humidity, and it may also enrich nutrient poor sites (Quinty and Rochefort 1997). In our experiments, straw did not significantly increase revegetation. Possibly longer term results may show that straw cover aids revegetation, but it did not in the first year. In addition, our field site had higher nutrients than those of Quinty and Rochefort's study in eastern Québec. The Seba Beach harvested site had higher levels and wider ranges for total P, NO_3^--N and NH_4^+-N (Table 5-10). The higher nutrient levels may explain the difference in the straw cover results, as any possible nutrient enhancement by the straw may not have been necessary to greatly improve the site for vegetation growth.

Although valuable results have been obtained from these top spit experiments, certain measures could have improved the experiments. One improvement would have been to randomly scatter the different treatment and control plots among the chosen harvested bays, reducing any possible bay effect on a particular treatment. Limitations of mechanical spreaders of the top spit material would need to be considered though. For example, timing experiments would need to be designed in such a way that a spreader would still be able to access the later treatment plots, even after the earlier treatment plots had been applied. Another improvement would have been to identify the peatland vegetation used for top spit down to species and percent cover. This information would have made a good comparison for the top spit experiment results of species and percent cover. Unfortunately, the top spit material was not always gathered with my knowledge, as industry often works within its constraints of time, machine availability, and manpower. Another improvement would have been to grow the top spit in ideal conditions. Although some preliminary work showed that the top spit was viable [4], further work is needed to more accurately compare establishment and growth of top spit on field and greenhouse (ideal) conditions.

5.6 Conclusions

The use of top spit is a viable technique for peatland restoration for this site. For vegetation cover, spring appears to be the best time for top spit application. In the timing experiments, high species diversity did not always correspond with high vegetation cover. The summer treatment established a more diversified plant community, but with lower vegetation cover than the spring treatments. The lag time between collection and application of the spring top spit is a confounding effect, and may have reduced the number of species which established. An early spring application of top spit, with rapid collection and application, may result in high vegetation cover and species richness. A thinner layer of top spit (1-2 cm) was also found to have higher vegetation cover levels than a thicker layer (2-4 cm). Therefore, more top spit is not necessarily better.

A second application of top spit on already established top spit plots significantly increased revegetation for such groups as mosses, bog shrubs, and peatland plants, compared to the original spring plots. Yet the second application treatments were usually significantly lower in number of species compared to the single application summer treatment. Thus, if in a single application of top spit, peatland plants such as moss and shrubs do not establish well, a second application of top spit may increase peatland plant revegetation levels.

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[4] As part of another experiment, bog and fen top spit was spread by hand on peat filled containers and place in a shade house at the Devonian Gardens, Alberta, and in the field at Seba Beach, Alberta. The experiment was stopped before completion, as a portion of the experimental containers were ruined.

Both our bog and poor fen top spit treatments had higher levels of revegetation compared to the control treatment with no top spit additions. At this site, poor fen top spit treatments had a higher number of peatland plants than bog top spit treatments, probably due to the more fen like chemical characteristics of the field. A straw covering also did not significantly aid in revegetation, possibly due to the higher nutrient levels already existing on the exposed peat surface. These results cover only one season of growth and may change with time.

Although the use of top spit has given promising results, there are some limitations to this revegetation technique which should be noted. A natural peatland, which serves as the propagule source for the harvested site, is negatively affected by the removal of the top spit layer. The damage to natural peatlands can be reduced by confining the damage to a small area, by removing only a thin layer of top spit, and by using top spit from areas which are already designated for peat harvesting. The gathering and application of top spit should follow in rapid succession to minimize top spit dessication and exposure. Early spring was the most successful time of top spit application in terms of revegetation cover. The gathering and application of top spit should be done when frost levels are at the desired depth in the source area to gather top spit (a depth of 10-20 cm), and while there is still enough frost in the harvested site to support heavy machinery. At this time, machinery such as a bull dozer or cat could scrape off the thawed surface layer, while moderating the impact on the underlying frozen peat. Weather, such as heavy warm spring rains, could possibly swiftly change the field conditions, and thus co-ordination of top spit collection may be within a tight time period to make use of frost levels within the peatland sites. Therefore, although present top spit revegetation techniques are useful, there are also some limitations.

Table 5-1. Snowfall for Entwistle*, Alberta, 1991-1995.

	Snowfall (cm)
Nov.1991 - Mar.1992	66
Nov.1992 - Mar.1993	60
Nov.1993 - Mar.1994	140
Nov.1994 - Mar.1995	40

Notes: * ~15 km away from the peatland site.
Data from Environment Canada (1994, and 1997)

Table 5-2. Vegetation lists of groups of peatland and nonpeatland plants for top spit timing and thickness experiments

Peatland plants		Nonpeatland plants	
Species name	Common name	Species name	Common name
Carex curta	Grey sedge	*Carex aenea*	Bronze sedge
Carex interior	Interior sedge	*Ceratodon purpureus*	
Eriophorum vaginatum	Cotton grass	*Leptobryum pyriforme*	
Scirpus microcarpus	Small flowered bulrush	*Bidens cernua*	Nodding beggarticks
Sedge species 1		*Potentilla norvegica*	Rough cinquefoil
Juncus bufonius	Toad rush	*Rumex crispus*	Curled dock
Typha latifolia	Cattail	*Epilobium spp.*	Fireweed
Aulacomnium palustre		*Trifoilum spp.*	Clover
Sphagnum angustifolium		*Ranunculus spp.*	Buttercup
Sphagnum magellanicum		*Cirsium arvense*	Canada thistle
Sphagnum fuscum		*Galium triflorum*	Small bedstraw
Polytrichum strictum		*Taraxacum officinale*	Dandelion
Polytrichum longisetum		*Equisetum arvense*	Field horsetail
Dicranum undulatum		*Lemna minor*	Common duckweed
Polia nutans		*Utricularia spp.*	Bladderwort
Drepanocladus aduncus		Small unidentified herbs	
Climacium dendroides		*Agrostis scabra*	Tickle grass
Ledum groenlandicum	Labrador tea	*Calamagrostis canadensis*	Marsh reed grass
Vaccinium oxycoccos	Bog cranberry	*Echinochloa crusgalli*	Barnyard grass
Vaccinium vitis-idaea	Mountain cranberry	Grass species 1	
Rubus chamaemorus	Cloudberry	Grass species 2	
Salix spp.	Willow	Grass shoots	
Betula spp.	Birch		

Table 5-3. Vegetation lists of groups of disturbed area species and nondisturbed area species for top spit timing and thickness experiments

Disturbed area species		Nondisturbed area species	
Species name	Common name	Species name	Common name
Carex aenea	Bronze sedge	*Carex curta*	Grey sedge
Bidens cernua	Nodding beggarticks	*Carex interior*	Interior sedge
Rumex crispus	Curled dock	*Eriophorum vaginatum*	Cotton grass
Epilobium spp.	Fireweed	*Scirpus microcarpus*	Small flowered bulrush
Trifoilum spp.	Clover	Sedge species 1	
Taraxacum officinale	Dandelion	*Juncus bufonius*	Toad rush
Agrostis scabra	Tickle grass	*Typha latifolia*	Cattail
Ceratodon purpureus		*Aulacomnium palustre*	
Leptobryum pyriforme		*Sphagnum angustifolium*	
		Sphagnum magellanicum	
		Sphagnum fuscum	
		Polytrichum strictum	
		Polytrichum longisetum	
		Dicranum undulatum	
		Polia nutans	
		Drepanocladus aduncus	
		Climacium dendroides	
		Ledum groenlandicum	Labrador tea
		Vaccinium oxycoccos	Bog cranberry
		Vaccinium vitis-idaea	Mountain cranberry
		Rubus chamaemorus	Cloudberry
		Salix spp.	Willow
		Betula spp.	Birch
		Potentilla norvegica	Rough cinquefoil
		Ranunculus spp.	Buttercup
		Cirsium arvense	Canada thistle
		Galium triflorum	Small bedstraw
		Equisetum arvense	Field horsetail
		Lemna minor	Common duckweed
		Utricularia spp.	Bladderwort
		Small unidentified herbs	
		Calamagrostis canadensis	Marsh reed grass
		Echinochloa crusgalli	Barnyard grass
		Grass species 1	
		Grass species 2	
		Grass shoots	

Table 5-4. Vegetation lists of groups of peatland and nonpeatland plants for top spit type experiments

Peatland plants		Nonpeatland plants	
Species name	Common name	Species name	Common name
Carex curta	Grey sedge	*Ceratodon purpureus*	
Carex interior	Interior sedge	*Bidens cernua*	Nodding beggarticks
Eriophorum vaginatum	Cotton grass	*Potentilla norvegica*	Rough cinquefoil
Scirpus microcarpus	Small flowered bulrush	*Rumex crispus*	Curled dock
Juncus bufonius	Toad rush	*Epilobium spp.*	Fireweed
Typha latifolia	Cattail	*Avena sativa*	Oats
Aulacomnium palustre		*Spergula arvensis*	Corn spurry
Sphagnum angustifolium		Small unidentified herbs	
Sphagnum magellanicum		*Agrostis scabra*	Tickle grass
Sphagnum fuscum		*Alopecurus aequalis*	Water foxtail
Polytrichum strictum		Grass species 1	
Dicranum undulatum		Grass shoots	
Polia nutans			
Ledum groenlandicum	Labrador tea		
Vaccinium oxycoccos	Bog cranberry		
Vaccinium vitis-idaea	Mountain cranberry		
Rubus chamaemorus	Cloudberry		
Salix spp.	Willow		
Betula spp.	Birch		

Table 5-5. Vegetation lists of groups of disturbed area species and nondisturbed area species for top spit type experiments

Disturbed area species		Nondisturbed area species	
Species name	Common name	Species name	Common name
Bidens cernua	Nodding beggarticks	*Carex curta*	Grey sedge
Rumex crispus	Curled dock	*Carex interior*	Interior sedge
Epilobium spp.	Fireweed	*Eriophorum vaginatum*	Cotton grass
Spergularia arvensis	Corn spurry	*Scirpus microcarpus*	Small flowered bulrush
Agrostis scabra	Tickle grass	*Juncus bufonius*	Toad rush
Ceratodon purpureus		*Typha latifolia*	Cattail
		Aulacomnium palustre	
		Sphagnum angustifolium	
		Sphagnum magellanicum	
		Sphagnum fuscum	
		Polytrichum strictum	
		Dicranum undulatum	
		Polia nutans	
		Ledum groenlandicum	Labrador tea
		Vaccinium oxycoccos	Bog cranberry
		Vaccinium vitis-idaea	Mountain cranberry
		Rubus chamaemorus	Cloudberry
		Salix spp.	Willow
		Betula spp.	Birch
		Potentilla norvegica	Rough cinquefoil
		Avena sativa	Oats
		Small unidentified herbs	
		Alopecurus aequalis	Water foxtail
		Grass species 1	
		Grass shoots	

Table 5-6. Peat chemistry on harvested bays 7 and 8, compared to 1.5 standard deviation range of the harvested site, 1994-1995

	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)	P (mg/kg)	S (mg/kg)	NO3-N (mg/kg)	NH4-N (mg/kg)
1994								
Bay 7, sample 1	13107	1857	236.9	279.7	472.8	3019	---	---
Bay 8, sample 1	5882	**2360**	278.4	**1606**	428.1	1036	---	---
Bay 8, sample 2	5490	1470	168.7	736.1	364.0	870	---	---
± 1.5 standard deviation	4621-14548	666-2336	0-1783	0-859	234-575	15-4132	---	---
1995								
Bay 7, sample 1	10353	1459	199.6	478.6	381.1	2018	0.9	80.0
Bay 8, sample 1	5567	1731	422.7	**935.5**	496.5	1216	0.0	13.4
Bay 8, sample 2	4651	1133	209.3	410.8	238.2	827.4	0.0	121.4
± 1.5 standard deviation	3753-13359	542-1976	0-2740	0-540	161-579	0-4436	0-72	0-323

Note: Numbers in bold lie outside the range of ±1.5 standard deviation.

Table 5-7. Vegetation list of top spit timing experiments

Category	Species name	Common name	Winter 1-2 cm	Winter 2-4 cm	Spring 1-2 cm	Spring 2-4 cm	Summer 1-2 cm	Controls	2nd application over Spring 1-2 cm plots	2nd application over Spring 2-4 cm plots	2nd application over Control plots
Sedges, rushes, and cattails	*Carex aenea*	Bronze sedge	x	x	x	x		x	x	x	x
	Carex curta	Grey sedge	x	x	x		x	x			x
	Carex interior	Interior sedge			x	x	x		x	x	
	Eriophorum vaginatum	Cotton grass	x				x	x		x	x
	Scirpus microcarpus	Small flowered bulrush	x	x	x	x	x	x	x	x	x
	Sedge species 1									x	x
	Juncus bufonius	Toad rush				x	x				
	Typha latifolia	Cattail	x	x			x	x			
Moss	*Aulacomnium palustre*				x	x	x	x	x	x	x
	Sphagnum angustifolium		x		x	x	x	x	x	x	x
	Sphagnum magellanicum				x		x		x	x	x
	Sphagnum fuscum						x				
	Polytrichum strictum				x	x	x		x	x	x
	Polytrichum longisetum									x	
	Dicranum undulatum				x	x			x	x	x
	Polia nutans				x	x	x		x	x	
	Drepanocladus aduncus							x			
	Climacium dendroides								x		
	Ceratodon purpureus				x	x	x		x		x
	Leptobryum pyriforme						x				
Bog shrubs	*Ledum groenlandicum*	Labrador tea					x		x	x	x
	Vaccinium oxycoccos	Bog cranberry					x			x	
	Vaccinium vitis-idaea	Mountain cranberry					x			x	
	Rubus chamaemorus	Cloudberry					x		x	x	x

Table 5-7 continued. Vegetation list of top spit timing experiments

Category	Species name	Common name	Winter 1-2 cm	Winter 2-4 cm	Spring 1-2 cm	Spring 2-4 cm	Summer 1-2 cm	Controls	2nd application over Spring 1-2 cm plots	2nd application over Spring 2-4 cm plots	2nd application over Control plots
Fen shrubs	*Salix spp.*	Willow						x	x	x	
	Betula spp.	Birch							x		
Herbs	*Bidens cernua*	Nodding beggarticks	x	x	x	x	x	x	x	x	x
	Potentilla norvegica	Rough cinquefoil					x				
	Rumex crispus	Curled dock		x					x		
	Epilobium spp.	Fireweed					x				x
	Trifoilum spp.	Clover					x				
	Ranunculus spp.	Buttercup	x								
	Cirsium arvense	Canada thistle					x				
	Galium triflorum	Small bedstraw	x					x			
	Taraxacum officinale	Dandelion									x
	Equisetum arvense	Field horsetail					x				
	Lemna minor	Common duckweed	x	x							
	Utricularia spp.	Bladderwort	x	x							
	Small unidentified herbs		x	x	x	x	x	x	x	x	x
Grasses	*Agrostis scabra*	Tickle grass	x	x	x		x	x	x	x	
	Calamagrostis canadensis	Marsh reed grass			x		x		x		
	Echinochloa crusgalli	Barnyard grass					x				
	Grass species 1			x	x	x					
	Grass species 2						x				
	Grass shoots		x	x	x	x	x	x	x		x
Total number of species			14	12	17	14	30	14	21	20	18

Table 5-8. Significant differences in Second application treatments compared to Spring and Summer treatments determined by Mann-Whitney U - Wilcoxon Rank Sum W tests for vegetation cover and number of species

Vegetation Cover			Number of Species		
2nd application of top spit over Spring 1-2 cm plots > Spring 1-2 cm plots	2nd application of top spit over Spring 2-4 cm plots > Spring 2-4 cm plots		2nd application of top spit over Spring 1-2 cm plots > Spring 1-2 cm plots	2nd application of top spit over Spring 2-4 cm plots > Spring 2-4 cm plots	
Nondisturbed area species Peatland species	Moss Bog shrubs Nondisturbed area species Peatland species		Total vegetation Moss Nondisturbed area species Peatland species	Total vegetation Moss Bog shrubs Nondisturbed area species Peatland species	
2nd application of top spit over Spring 1-2 cm plots > Summer 1-2 cm plots	2nd application of top spit over Spring 2-4 cm plots < Summer 1-2 cm plots	No significant difference	2nd application of top spit over Spring 1-2 cm plots > Summer 1-2 cm plots	2nd application of top spit over Spring 2-4 cm plots < Summer 1-2 cm plots	No significant difference
Total vegetation Sedges, rushes, cattails Fen shrubs Disturbed area species Nondisturbed area species Nonpeatland species Peatland species	Grass	Moss Bog shrubs Herbs	Fen shrubs	Total vegetation Moss Herbs Grass Nondisturbed area species Peatland species	Sedges, rushes, cattails Bog shrubs Disturbed area species Nonpeatland species

Table 5-9. Vegetation list for top spit type experiments

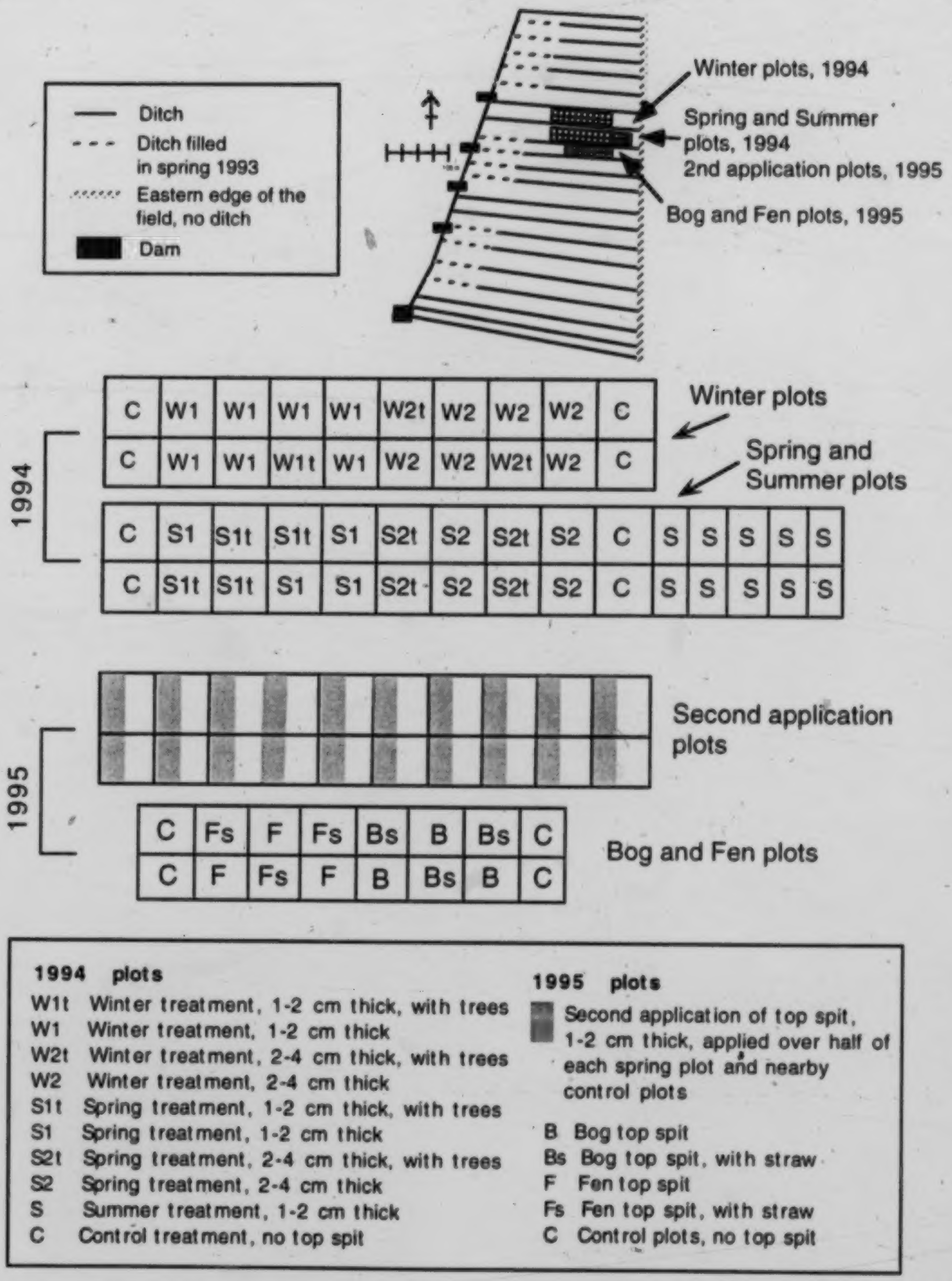
Category	Species name	Common name	Bog top spit with straw	Bog top spit without straw	Fen top spit with straw	Fen top spit without straw	Controls
Sedges, rushes, and cattails	*Carex curta*	Grey sedge	x	x	x	x	x
	Carex interior	Interior sedge				x	
	Eriophorum vaginatum	Cotton grass		x			
	Scirpus microcarpus	Small flowered bulrush	x	x	x	x	x
	Juncus bufonius	Toad rush	x	x	x	x	
	Typha latifolia	Cattail	x		x	x	x
Moss	*Aulacomnium palustre*		x	x	x	x	
	Sphagnum angustifolium		x	x	x	x	
	Sphagnum magellanicum			x	x	x	
	Sphagnum squarrosum					x	
	Polytrichum strictum		x	x	x	x	
	Dicranum undulatum		x	x			
	Polia nutans					x	
	Ceratodon purpureus		x				
Bog shrubs	*Ledum groenlandicum*	Labrador tea		x	x		
	Vaccinium oxycoccos	Bog cranberry		x			
	Vaccinium vitis-idaea	Mountain cranberry			x	x	
	Rubus chamaemorus	Cloudberry	x	x		x	
Fen shrubs	*Salix spp.*	Willow	x	x	x	x	
	Betula spp.	Birch					x

Table 5-9 continued. Vegetation list for top spit type experiments

Category	Species name	Common name	Bog top spit with straw	Bog top spit without straw	Fen top spit with straw	Fen top spit without straw	Controls
Herbs	*Bidens cernua*	Nodding beggarticks	x	x	x	x	x
	Potentilla norvegica	Rough cinquefoil		x			
	Rumex crispus	Curled dock		x			
	Epilobium spp.	Fireweed	x	x		x	
	Avena sativa	Oats	x		x		
	Spergularia arvensis	Corn spurry	x		x		
	Small unidentified herbs		x	x	x	x	x
Grasses	*Agrostis scabra*	Tickle grass	x	x	x	x	x
	Alopecurus aequalis	Water foxtail					x
	Grass species 1				x	x	x
	Grass shoots						x
Total number of species			17	19	17	19	10

Table 5-10. Nutrient differences between the Eastern Québec and the Seba Beach harvested sites in water chemistry.
Annual means (and ranges) presented.

	n	Year(s) meaned	Total P (mg/L)	NO3--N (mg/L)	NH4+-N (mg/L)
Eastern Québec	3	1993	0 (<0.6-<0.6)	0.3 (0-0.6)	1.6 (1.6-1.6)
Seba Beach	30	1993-1995	0.52 (0.09-1.26)	0.19 (0.01-2.65)	3.19 (0-9.53)


Ditch
Ditch filled in spring 1993
Eastern edge of the field, no ditch
Dam
Winter plots, 1994
Spring and Summer plots, 1994
2nd application plots, 1995
Bog and Fen plots, 1995
1994
Winter plots
Spring and Summer plots
1995
Second application plots
Bog and Fen plots

C	W1	W1	W1	W1	W2t	W2	W2	W2	C
C	W1	W1	W1t	W1	W2	W2	W2t	W2	C

C	S1	S1t	S1t	S1	S2t	S2	S2t	S2	C	S	S	S	S	S
C	S1t	S1t	S1	S1	S2t	S2	S2t	S2	C	S	S	S	S	S

C	Fs	F	Fs	Bs	B	Bs	C
C	F	Fs	F	B	Bs	B	C

1994 plots

W1t	Winter treatment, 1-2 cm thick, with trees
W1	Winter treatment, 1-2 cm thick
W2t	Winter treatment, 2-4 cm thick, with trees
W2	Winter treatment, 2-4 cm thick
S1t	Spring treatment, 1-2 cm thick, with trees
S1	Spring treatment, 1-2 cm thick
S2t	Spring treatment, 2-4 cm thick, with trees
S2	Spring treatment, 2-4 cm thick
S	Summer treatment, 1-2 cm thick
C	Control treatment, no top spit

1995 plots

▨	Second application of top spit, 1-2 cm thick, applied over half of each spring plot and nearby control plots
B	Bog top spit
Bs	Bog top spit, with straw
F	Fen top spit
Fs	Fen top spit, with straw
C	Control plots, no top spit

Figure 5-1. Experimental design of top spit plots.

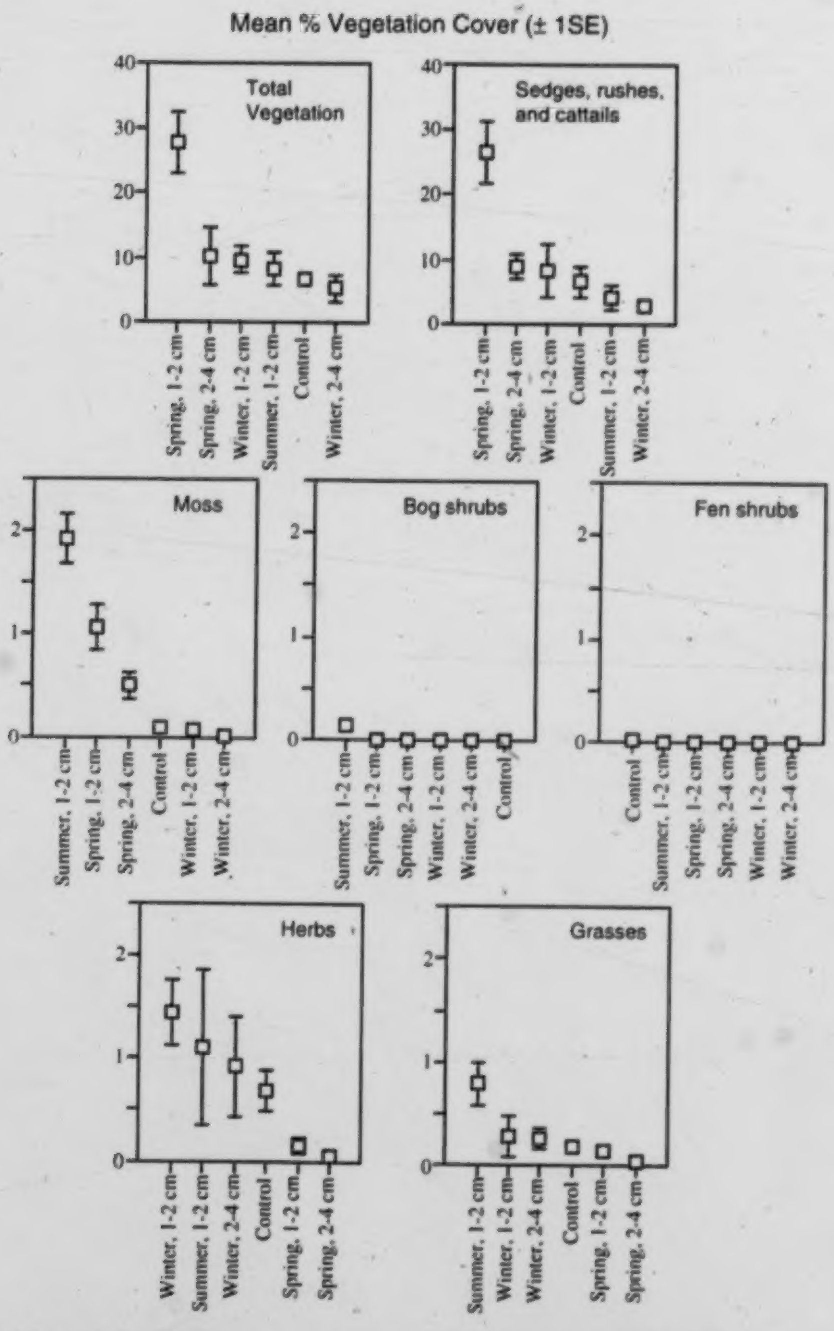


Figure 5-2a. Mean percent vegetation cover (± 1 standard error) of vegetation categories of top spit timing and thickness experiments. Treatments are listed in rank order as outlined in Figure 5-3a.

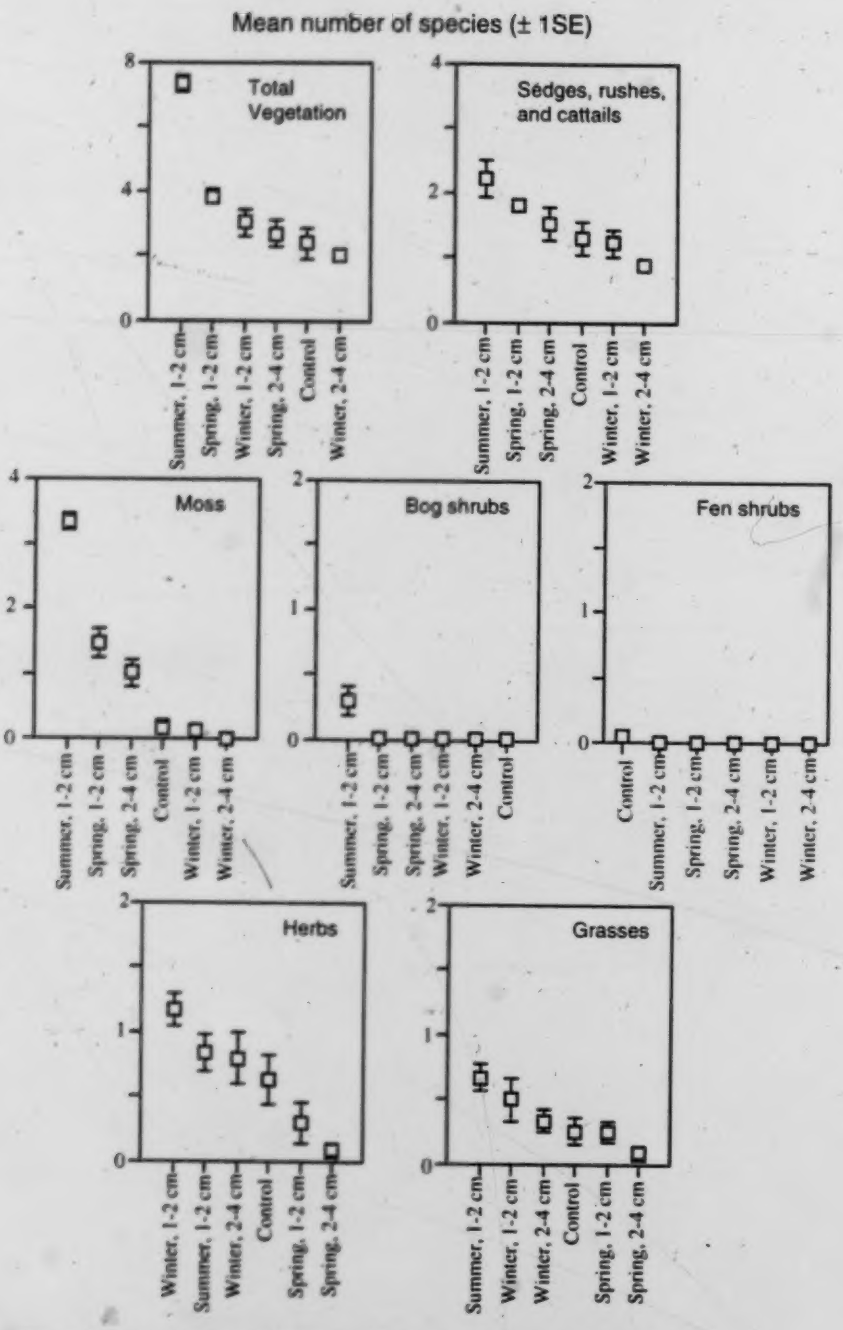


Figure 5-2b. Mean number of species (± 1 standard error) of vegetation categories of top spit timing and thickness experiments. Treatments are listed in rank order as outlined in Figure 5-3a.

Vegetation Cover

Total vegetation

Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Summer 1-2 cm	Control	Winter 2-4 cm
42.1	25.9	21.1	21.1	21.0	15.8

Sedges, rushes, cattails

Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Control	Summer 1-2 cm	Winter 2-4 cm
42.4	27.8	21.0	20.9	17.9	16.9

Moss

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Control	Winter 1-2 cm	Winter 2-4 cm
43.1	35.8	27.1	14.9	14.6	11.5

Bog shrubs

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Winter 2-4 cm	Control
34.5	22.5	22.5	22.5	22.5	22.5

Herbs

Winter 1-2 cm	Summer 1-2 cm	Winter 2-4 cm	Control	Spring 1-2 cm	Spring 2-4 cm
38.3	30.9	27.6	25.6	14.4	10.3

Grass

Summer 1-2 cm	Winter 1-2 cm	Winter 2-4 cm	Control	Spring 1-2 cm	Spring 2-4 cm
40.4	26.6	24.3	21.8	20.9	13.0

Number of Species

Total vegetation

Summer 1-2 cm	Spring 1-2 cm	Winter 1-2 cm	Spring 2-4 cm	Control	Winter 2-4 cm
44.5	30.9	22.8	19.1	17.0	12.8

Sedges, rushes, cattails

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Control	Winter 1-2 cm	Winter 2-4 cm
36.8	32.9	24.6	22.8	19.2	10.8

Moss

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Control	Winter 1-2 cm	Winter 2-4 cm
44.5	33.8	28.9	14.6	14.2	11.0

Bog shrubs

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Winter 2-4 cm	Control
34.5	22.5	22.5	22.5	22.5	22.5

Herbs

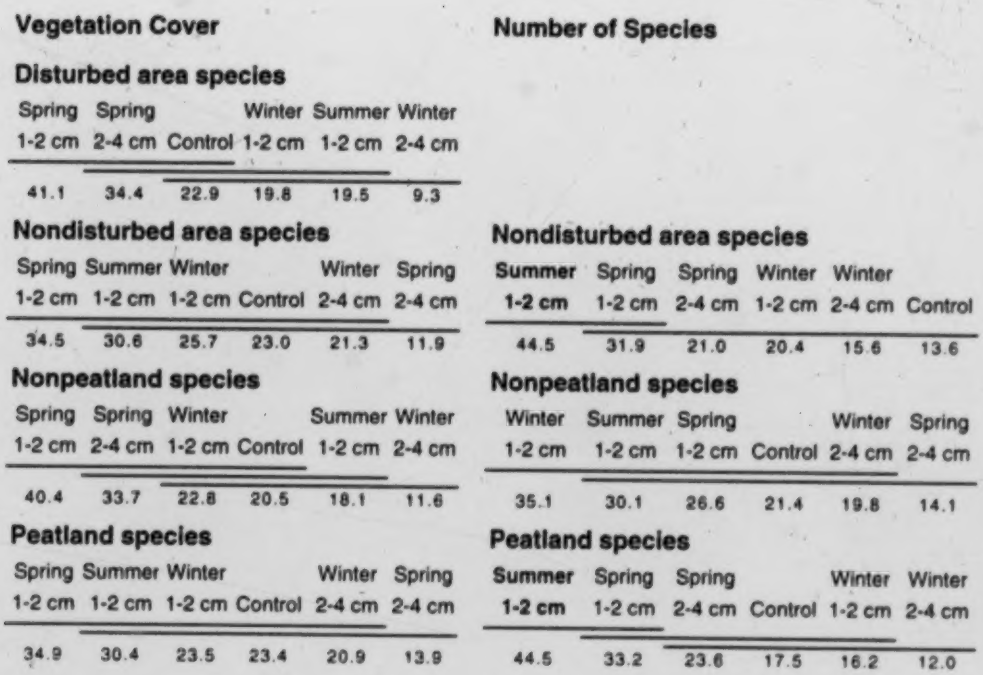
Winter 1-2 cm	Summer 1-2 cm	Winter 2-4 cm	Control	Spring 1-2 cm	Spring 2-4 cm
37.3	29.8	29.3	24.8	15.6	10.4

Grass

Summer 1-2 cm	Winter 1-2 cm	Winter 2-4 cm	Control	Spring 1-2 cm	Spring 2-4 cm
36.9	28.8	25.4	21.6	21.0	13.4

Figure 5-3a. Comparisons of mean ranks of the top spit timing and thickness treatments determined by Kruskal-Wallis 1-way anovas, followed by Tukey-type multiple comparison tests, for vegetation cover and number of species.

The vegetation categories Fen shrubs had no significant differences among the treatments. Treatments which are significantly different than the control are outlined in bold.



Vegetation Cover

Disturbed area species

Spring 1-2 cm	Spring 2-4 cm	Control	Winter 1-2 cm	Summer 1-2 cm	Winter 2-4 cm
41.1	34.4	22.9	19.8	19.5	9.3

Nondisturbed area species

Spring 1-2 cm	Summer 1-2 cm	Winter 1-2 cm	Control	Winter 2-4 cm	Spring 2-4 cm
34.5	30.6	25.7	23.0	21.3	11.9

Nonpeatland species

Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Control	Summer 1-2 cm	Winter 2-4 cm
40.4	33.7	22.8	20.5	18.1	11.6

Peatland species

Spring 1-2 cm	Summer 1-2 cm	Winter 1-2 cm	Control	Winter 2-4 cm	Spring 2-4 cm
34.9	30.4	23.5	23.4	20.9	13.9

Number of Species

Nondisturbed area species

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Winter 1-2 cm	Winter 2-4 cm	Control
44.5	31.9	21.0	20.4	15.6	13.6

Nonpeatland species

Winter 1-2 cm	Summer 1-2 cm	Spring 1-2 cm	Control	Winter 2-4 cm	Spring 2-4 cm
35.1	30.1	26.6	21.4	19.8	14.1

Peatland species

Summer 1-2 cm	Spring 1-2 cm	Spring 2-4 cm	Control	Winter 1-2 cm	Winter 2-4 cm
44.5	33.2	23.6	17.5	16.2	12.0

Figure 5-3b. Comparisons of mean ranks of the top spit timing and thickness treatments determined by Kruskal-Wallis 1-way anovas, followed by Tukey-type multiple comparison tests, for vegetation cover and number of species. Treatments which are significantly different than the control are outlined in bold.

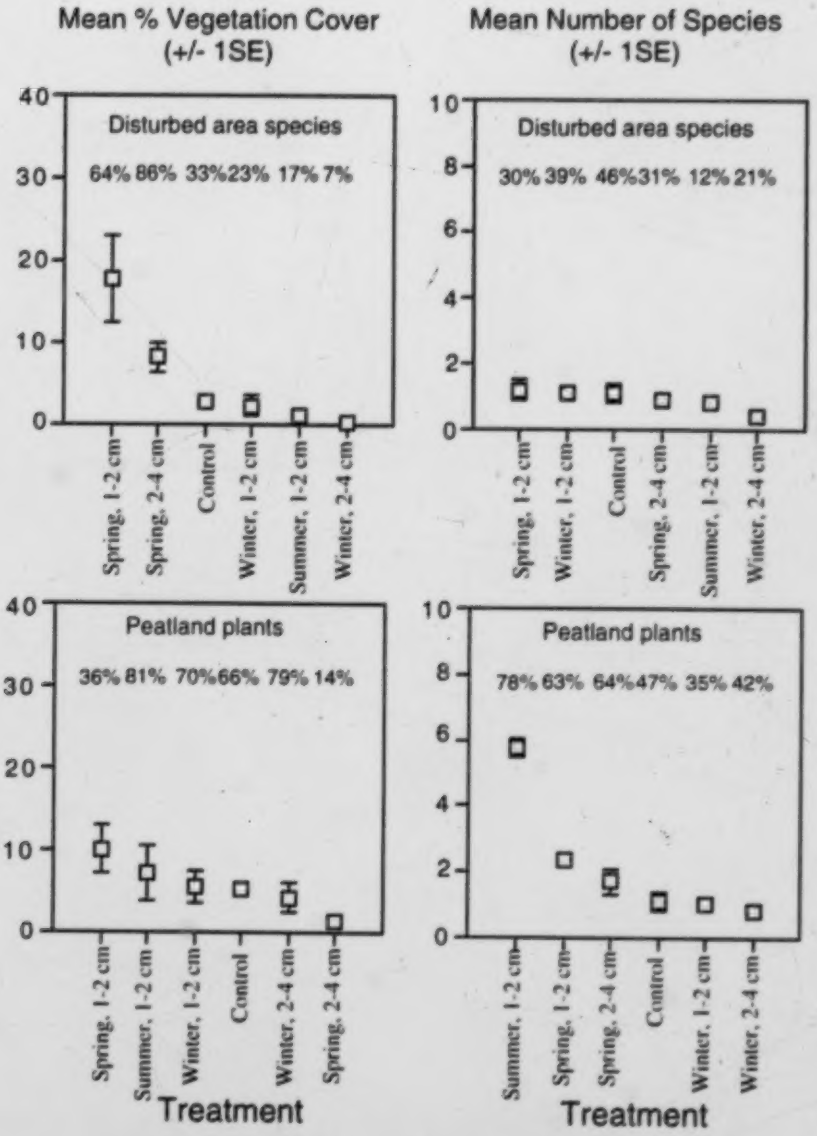


Figure 5-4. Mean percent vegetation cover and mean number of species (+/- 1 standard error) of the disturbed area species and peatland species vegetation categories for the top spit timing and thickness experiments.

Treatments are in rank order as outlined in Figure 5-3b. Percentages of the vegetation group from the total cover or number of species are listed at the top section of each graph.

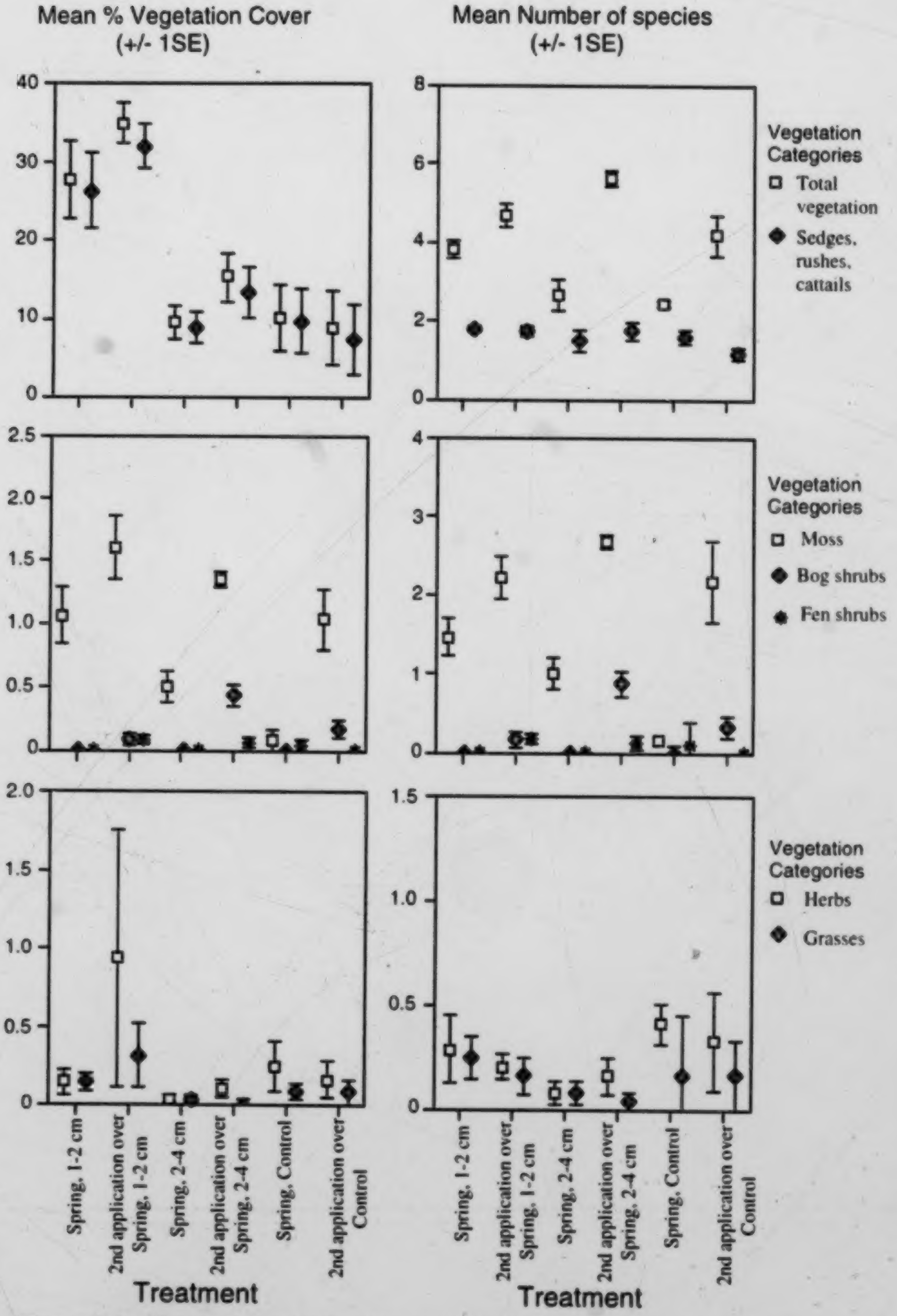


Figure 5-5. Mean percent vegetation cover and mean number of species (± 1 standard error) of vegetation categories for the Spring and second application plots.

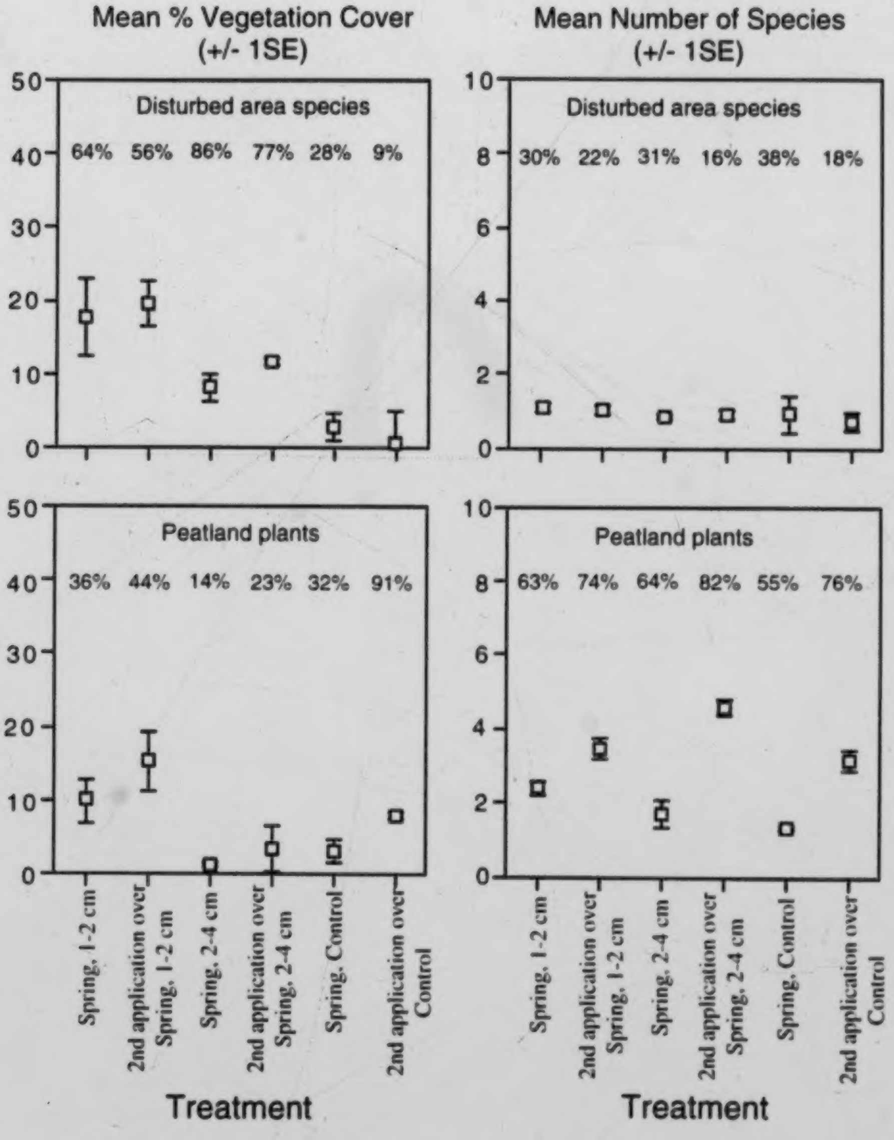


Figure 5-6. Mean percent vegetation cover and mean number of species (+/- 1 standard error) of the disturbed area species and peatland species vegetation categories for the Spring and second application plots.

Percentages of the vegetation group from the total cover or number of species are listed at the top section of each graph.

Vegetation Cover

Sedges, rushes, cattails

Fen without straw	Fen with straw	Bog without straw	Bog with straw	Control
15.0	10.0	8.7	5.0	5.0

Moss

Fen with straw	Fen without straw	Bog without straw	Bog with straw	Control
14.0	12.5	8.2	7.3	2.5

Number of Species

Total vegetation

Bog without straw	Fen with straw	Fen without straw	Bog with straw	Control
13.7	12.2	9.5	6.7	2.5

Sedges, rushes, cattails

Fen with straw	Fen without straw	Bog without straw	Bog with straw	Control
13.0	12.7	10.3	5.0	3.3

Moss

Fen with straw	Fen without straw	Bog without straw	Bog with straw	Control
13.3	12.2	9.2	7.3	2.5

Nondisturbed area species

Fen with straw	Fen without straw	Bog with straw	Bog without straw	Control
15	10.8	8.2	8	2.5

Peatland species

Fen with straw	Fen without straw	Bog without straw	Bog with straw	Control
14.7	12.3	8.3	6.7	2.5

Figure 5-7. Comparison of mean ranks of bog and fen top spit treatments determined by Kruskal-Wallis 1-way anovas, followed by Tukey-type multiple comparison tests, for vegetation cover and number of species.

The vegetation categories Bog shrubs, Fen shrubs, Grasses, Herbs, Disturbed area species, and Nonpeatland species had no significant differences among the treatments.

Treatments which are significantly different from the control are outlined in bold.

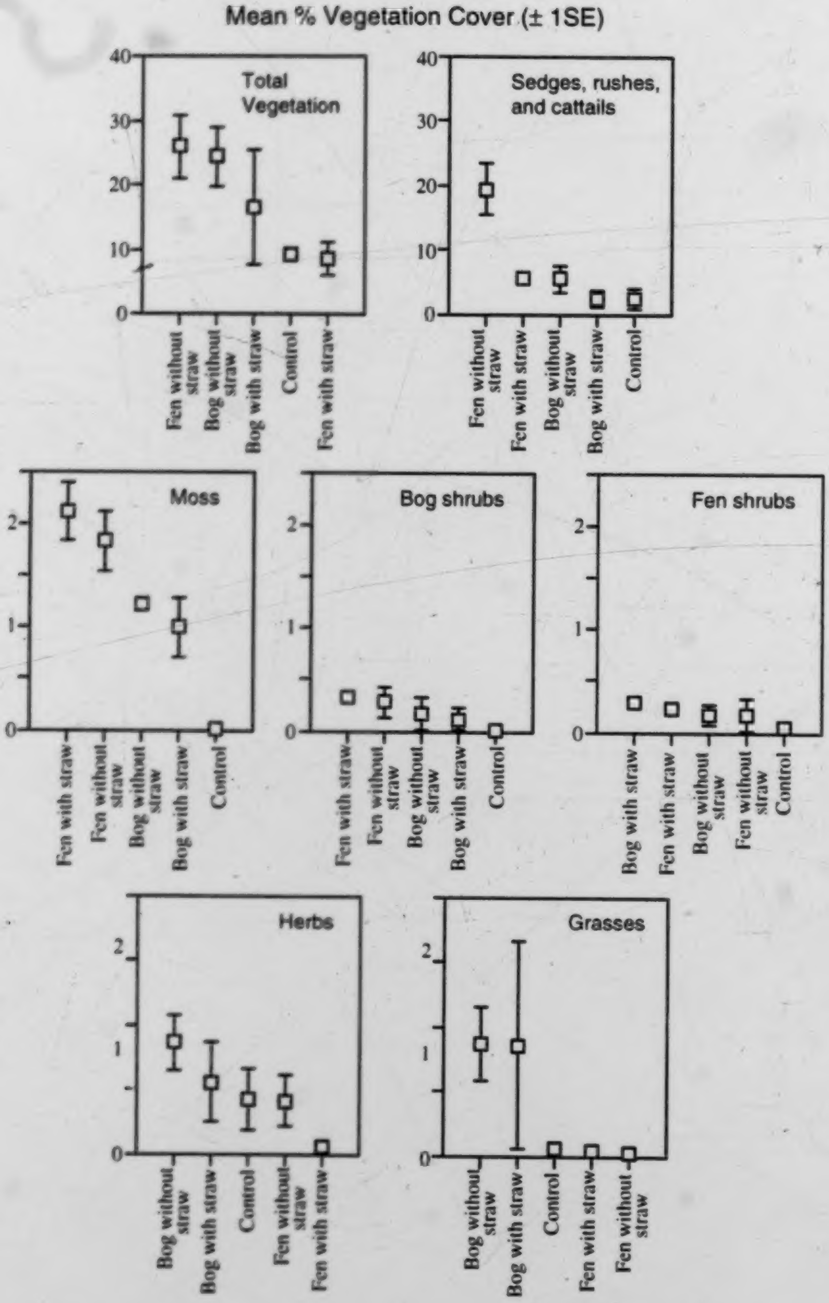


Figure 5-8a. Mean percent vegetation cover (± 1 standard error) of vegetation categories for the bog and fen top spit treatments.
Treatments are listed in rank order as outlined in Figure 5-7 and Kruskal-Wallis 1-way anovas.

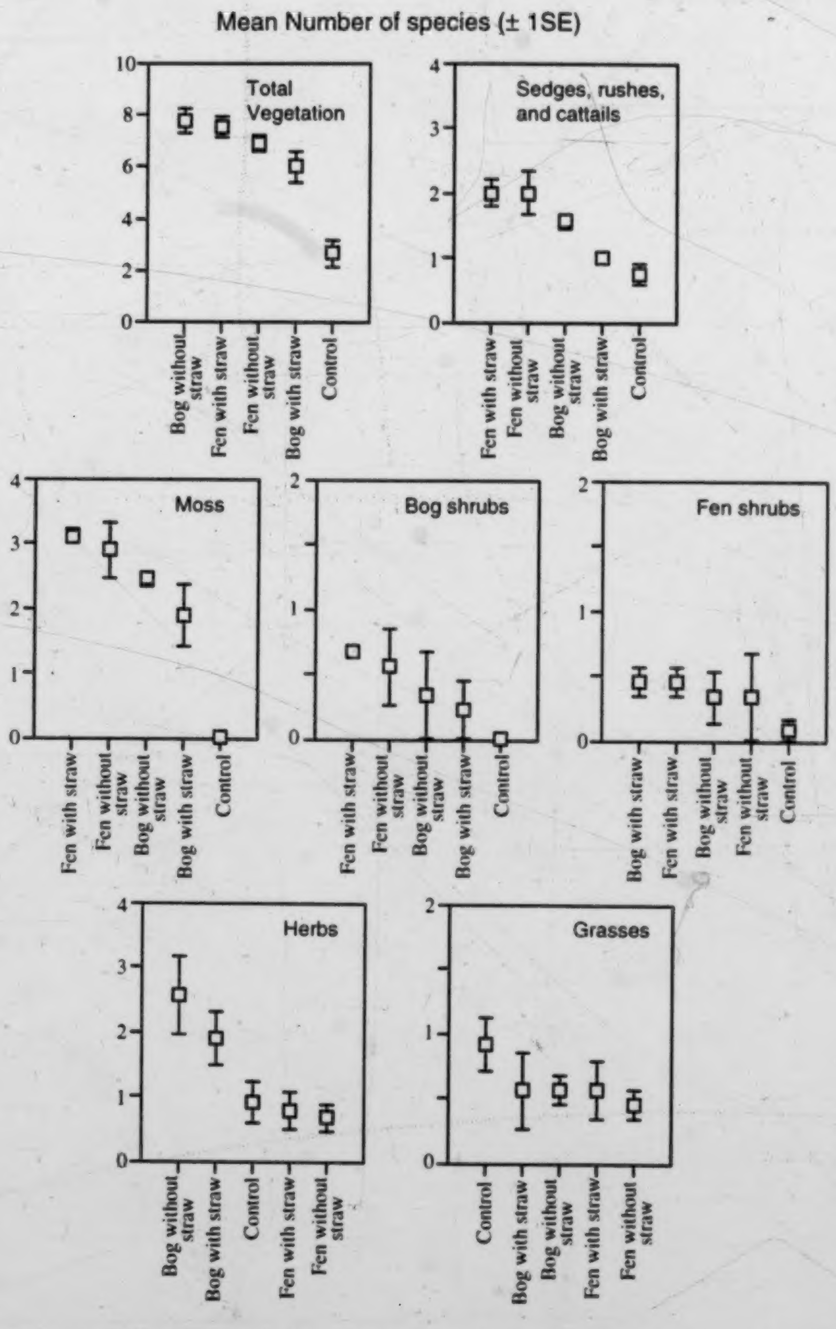


Figure 5-8b. Mean number of species (± 1 standard error) of vegetation categories for the bog and fen top spit treatments.
Treatments are listed in rank order as outlined in Figure 5-7 and Kruskal-Wallis 1-way anovas.

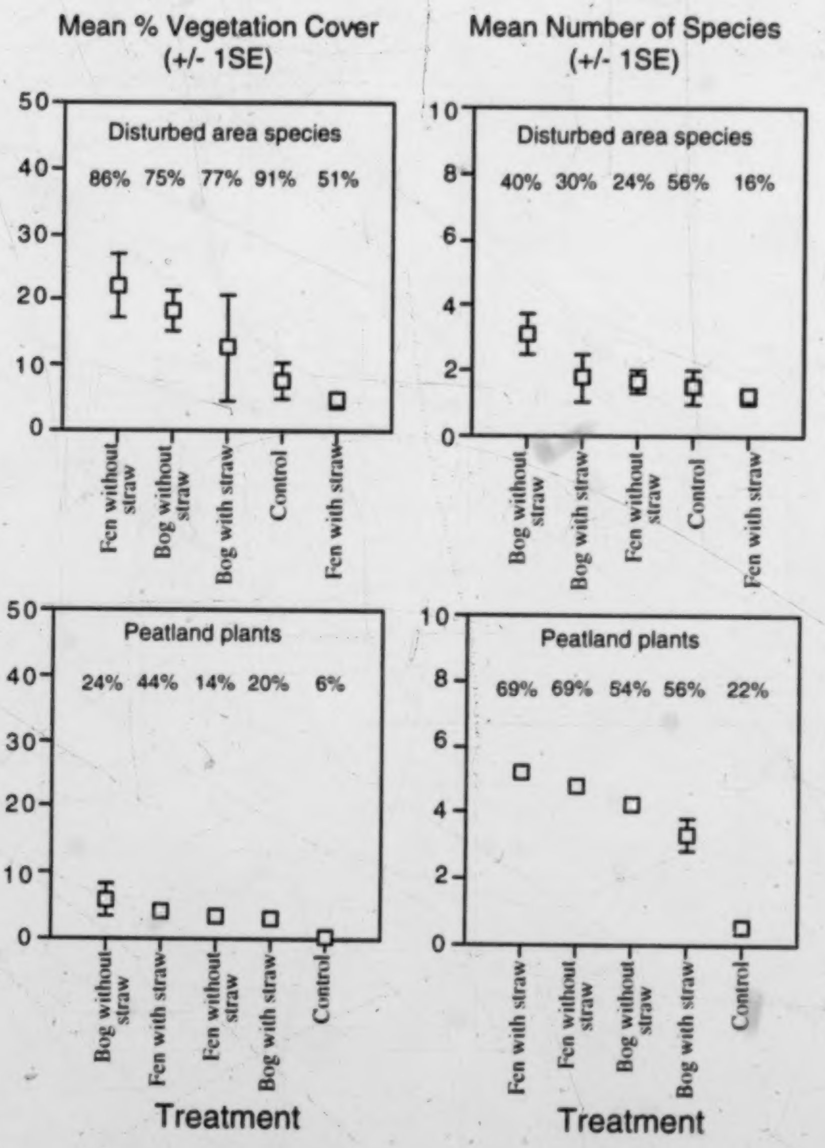


Figure 5-9. Mean percent vegetation cover and mean number of species (+/- 1 standard error) of the disturbed area species and peatland species vegetation categories for the bog and fen top spit treatments.

Treatments are in rank order as outlined in Figure 5-7 and Kruskal-Wallis 1-way anovas. Percentages of the vegetation group from the total cover or number of species are listed at the top section of each graph.

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Chapter 6

Conclusions

6.1 Thesis objectives

Peatland restoration in Canada is a young discipline, with research starting in this decade. To renew, repair and reconstruct a harvested peatland to become a functioning, carbon accumulating, dynamically integrated ecosystem is an ambitious project. To expand foundational knowledge of harvested sites, this thesis focused on two main objectives. The first objective is to investigate the differences between harvested and natural peatlands. For this research, a harvested and neighbouring natural site in Seba Beach, Alberta were intensively studied. Site chemistry and hydrology were monitored and compared. Some additional sites from eastern Canada were also examined for peat and water chemistry. The second objective was to examine methods of re-introducing and establishing *Sphagnum* and other peatland plants on the harvested site. Various revegetation experiments were conducted. Experiments using surface peatland vegetation, called top spit, are reported in this thesis.

This research, examining the characteristics of a harvested peatland and various restoration strategies, has been experimental ecology. This investigation has not been process oriented, as the study of peatland restoration first needs correlative biotic and physical baseline data. The basic foundational research is still needed. The focus has been the study of hydrological and geochemical regimes, and revegetation experiments. This groundwork research has given insights particular to the Seba Beach harvested site, and is relevant to problems common to harvested peatlands in general. Thus, valuable experiences can be tied together and formulated into specific and general restoration guidelines. Recommendations for the restoration of the Seba Beach harvested site are outlined in this chapter, followed by restoration guidelines that can be applied to harvested peatlands generally.

6.2 Chemical differences on the harvested peatland

Peat harvesting at the Alberta Seba Beach site has affected the site chemistry with the removal of the surface ombrotrophic bog peat. The harvested site has peat and water chemical conditions more similar to a poor to moderate-rich fen site, with relatively high nutrient levels. Nutrient levels are elevated compared to undisturbed peatlands and elemental levels are more variable. Other harvested sites in eastern Canada show similar trends (Wind-Mulder et al. 1996). Harvested peatlands have more variation due to more heterogeneous conditions, including the extent to which fen peat is exposed, differing moisture levels, and amount of vegetation cover.

Over the five year study period, the following was observed in the harvested area: the water chemistry showed few significant differences from year to year; the peat chemistry had many significant differences. Changing water levels and vegetation cover may have helped to form the intricate changing patterns in the peat chemistry, during these first rewetting years. These changes in water levels and vegetation cover may have also affected changing nitrogen levels at the site, as aqueous NH_4^+-N and available NO_3-N in the peat were significantly reduced during the study period. In the natural area, no significant yearly differences were found.

6.3 Hydrological differences in the harvested peatland

Hydrological studies of the Seba Beach harvested site found that water levels are low and variable. The destruction of a functioning acrotelm, and the exposure of the underlying more humified, compacted peat layer has significantly altered water levels and increased water level fluctuation. The neighbouring natural area had water levels that were much more steady and consistently close to the vegetation surface. Over the five year study period with the addition of primary and secondary dams, water levels did increase over the harvested site, although they were still variable. With the rising water levels, flooded pools formed on the site. These pools may increase the storage capacity close to the peat surface and thereby decrease water fluctuation on the harvested site. Rising water levels have also saturated low lying areas of the field, and caused the rise in peat surface level.

6.4 Top spit applications

Experiments in top spit applications indicated that this is a promising method to encourage and enhance the revegetation of peatland plants. A thinner layer of top spit (1-2 cm) resulted in greater vegetative cover and number of species compared to a thicker top spit application (2-4 cm). Spring application of top spit material resulted in the greatest vegetation cover, while summer application data showed the highest species richness and highest proportion of peatland plant species. The delay of five months from collection of the top spit material and application for the spring treatment may have reduced viability of a number of species. Rapid collection and application of top spit material is advised to minimize top spit exposure and desiccation. If with a single application of top spit, peatland plants do not establish well, a second application of top spit may increase peatland revegetation levels. On the Seba Beach harvested site, poor fen top spit was more successful in revegetation measures than bog top spit. A straw cover on the top spit plots did not significantly increase revegetation, possibly due to the high nutrient levels found on this site.

6.5 Restoration recommendations for the Seba Beach harvested site

From what we have learned in this thesis work, a number of restoration recommendations can be made for the Seba Beach harvested site.

Rewetting of a harvested site is a prime concern for restoration, as high and stable water levels are necessary for the establishment of keystone *Sphagnum* species and other peatland plants. Thus, leveling of a site to be restored is recommended to aid in even rewetting of the area. Since the field in question already has experiments established, as well as rewetting procedures begun, field leveling is not recommended in this case.

It is recommended that ditches remain unfilled in the site to allow for more even rewetting of the site, and to increase the water storage capacity on the site. There has been concern that ditches should be filled in for safety reasons, as vegetation may eventually obscure ditch locations. With increased water levels, the peat ditch edges have been observed to slump, naturally refilling the ditches over time. In addition, mechanically filled in ditches were hazardous to walk across when flooded. Flooding made the ditch peat very soft and unstable. In case of either natural peat slumping or mechanically peat filled ditches, increased vegetation rooting should help to stabilize the peat in these areas over time.

A resurvey of the harvested site is recommended, as surface peat height has increased in some wet depressional areas, and decreased in other drier areas. The survey results would be used to calculate the necessary height of the primary dam, and the placement of internal dams. The primary dam could then be redesigned to retain the appropriate amount of water on the site, and allow any excess to flow off the site, with no dam deterioration. Internal dams, constructed in the ditches wherever the peat surface slopes more than 0.1 m/100 m, would aid in even retention of water on the restoration site (Streefkerk and Douglas 1994).

The Seba Beach harvested site has a number of depressional areas which have rewet, and even flooded, yet the northern end particularly has remained dry. The digging of small (less than 20 m in diameter, up to 50-60 cm deep (Beets 1992, Blankenburg and Kuntze 1988, Joosten 1992)) basins is recommended. These basins would retain water, increase detention storage capacity close to the harvested peat surface and help to moderate water level fluctuations.

This study should be continued using the recommended restoration plan for the remaining field area. Based on moisture observations from 1994-1995, the area is divided into three revegetation treatment sections of dry, moist, and wet.

6.5.1 Dry area revegetation recommendations

The dry area is considered to be too dry for good moss and sedge growth, and thus the spreading of top spit is not recommended. In this area, trees and shrubs are more likely to thrive. It is recommended that *Larix larcina* and *Picea mariana* tree seedlings be planted, as these trees grew in dry areas in earlier experiments (data not presented). Rooted *Andromeda polifolia* cuttings also grew well in dry parts of the site (data not presented), and are recommended for planting. These peatland trees and shrubs may moderate the microclimate of the dry areas, and with further rewetting water levels may increase over time. These improvements may provide a more suitable habitat for *Sphagnum* mosses and other peatland plants in the future.

6.5.2 Wet area revegetation recommendations

The wet treatment area has saturated to flooded peat. In these conditions bog and fen top spit plots have had promising amounts of growth of peatland sedges, moss and shrubs. Based on one year's data, fen top spit plots had more sedge growth, a lower proportion of weedy herbs and grasses, and double the mean *Sphagnum* cover compared to the bog top spit plots. It is recommended that fen top spit be located, transported to the field, chopped mechanically into pieces 0.5-2 cm in length (Campeau and Rochefort 1996), and spread in an 1-2 cm layer thick over the area. Although the top spit timing experiment had a confounding effect of varying lag times between collection and application of top spit material, early spring application appears to be the most successful with the highest vegetation cover. Early spring is recommended as the time to apply top spit. At this time that machinery can still be used without getting mired in the peat. Top spit collection, transportation to the site and application on the harvested field should be done in quick succession to preserve the viability of the vegetative material. Drying out of the material is to be avoided.

6.5.3 Moist area revegetation recommendations

The moist area is an area that has had more variation in its moisture level than the dry treatment area. Depending on weather conditions, the area's moisture levels may become more dry, or more wet, or just stay moist. Due to this possible variability, an experiment using a combination of the dry and wet treatments is suggested, using a Latin square design. The four moist bays would each be divided into four 50 m long treatment plots (Figure 6-1). The sequence of the four treatments should be randomly arranged on each bay. The four treatments would be 1/ planting peatland trees and shrubs, as outlined in the dry area (section 6.5.1), 2/ applying a thin layer of fen top spit, as outlined in the wet area (section 6.5.2), 3/ planting of peatland trees and shrubs over a thin layer of fen top spit, 4/ leaving the area with no top spit or added vegetation plantings, as a control area. Once the plots are set up, yearly measurements of the percent vegetation cover could be recorded by an industry member. On each plot, nine permanent stakes need to be evenly spaced, and vegetation cover should be recorded in a 2 m radius around each stake.

This experiment has many benefits. The design is simple and large scale, and will work easily with current industrial machinery. This experiment will also help to answer a number of questions for this field area. Such questions as: Will top spit grow in all the applied areas? Are some areas too dry for top spit? In those dry areas, do the trees and shrubs establish, and help to ameliorate the micro climate? Do those trees and shrubs later help to shelter seeds and spores? In the treatment plots with trees and top spit, does top spit establish and grow more successfully than in the plots without the peatland trees and shrubs? Does top spit need to be spread over all the field surface for peatland vegetation to establish, or will it spread into the control areas? Are there more weedy plants in the control plots compared to the other treatment plots? How do the vegetation levels change over time? Therefore, as this experiment is easy to execute, and it will help to answer many questions for both industry members and scientists, it is recommended to set up this experiment on the moist bays.

6.6 General recommendations for the restoration of harvested peatlands

Observations and experimental results can indicate further restoration measures that are specific to the Seba Beach harvested site, as described above. Additionally, many problems noted at this site are common to other vacuum harvested peatlands. For example, abandoned harvested sites have low levels of natural revegetation, and field conditions are harsh for vegetation re-establishment (Chapter 1, section 1-5). Chemistry studies of several harvested peatlands indicate that chemical levels are raised and more variable compared to natural peatlands (Chapter 2). Rewetting measures are needed to raise and moderate water levels on harvested sites (Chapter 4). The field experiences from the Seba Beach harvested site research may be reformed into general recommendations for other harvested peatlands. These general recommendations have been grouped into the three categories of chemistry, hydrology, and top spit recommendations, and are listed below.

6.6.1 Chemistry recommendations

- Before harvesting begins, chemical studies should be done for baseline data of the site. Also peat cores should be analyzed chemically to note chemical changes for the underlying successional layers in the peat deposit.

- Periodic chemical surveys of the site as harvesting is done will serve as check marks to the peat core studies, and will also illustrate the effects of drying, weathering, oxidation and compaction.

- A chemical survey at the completion of harvesting will indicate the final conditions now present for restoration measures.

- Raised nutrient conditions may mean that fertilization would not be beneficial or necessary, although nitrogen levels need to be considered separately from phosphorus levels.

- Periodic monitoring of the site during restoration will indicate how nutrient and element levels change with changing vegetation cover and increasing water levels.

6.6.2 Hydrology recommendations

- Adequate moisture levels, with only moderate water level fluctuations, are critical for *Sphagnum* moss and peatland plant establishment and growth. Thus, steps are needed to ensure these conditions on the harvested site.

- To aid in even rewetting of the harvested site, leveling of the field is first advised. If leveling is impractical, a series of bunds, or terraces may be constructed to evenly distribute water across the site. Internal dams in the ditches, constructed where the peat surface slopes more than 0.1 m/100 m, would aid in even rewetting of the site (Streefkerk and Douglas 1994).

- Ditches, previously used to drain the harvested site, can remain to distribute water across the site, and to act as storage reservoirs to increase the water storage capacity near the peat surface. A greater water storage capacity near the peat surface will help reduce water level fluctuations in the more humified peat remaining on the harvested site.

- Ditches should not cut into the underlying mineral layer. Mineral exposure in the ditch would influence the water chemistry, and may allow the downward seepage of water when water is needed on the peat surface.

- Measures should be taken to increase water levels on the site. Damming the outflow ditch would retain incoming water and precipitation on the site. The primary dam should be constructed to retain the appropriate amount of water on the site, and to allow any excess water to leave the site, without damaging and eroding the dam.

- Excess water from other harvested sites could also be directed to the restoring site, via ditches and/or pumping. This additional water may be especially beneficial in the beginning rewetting stages, as the harvested site should be resaturated as quickly as possible.

- Natural depressions or mechanically made hollows can serve to further increase the storage capacity on the peat surface. Depressions should not be greater than 20 m in diameter or deeper than 60 cm, to discourage wind and wave action disturbance (Beets 1992, Blankenburg and Kuntze 1988, Joosten 1992).

- Water levels should be monitored during the restoration process. Valuable information, such as increasing water levels, and the amount of water level fluctuation on the site can be recorded. Care should be taken to stabilize water level pipes or measurement rods to the mineral layer, to account for changing peat levels as water levels rise and the peat becomes resaturated.

- As water levels and soil moisture are significantly important for revegetation efforts, a study on the water budget of the harvested site by a qualified peatland hydrogeologist is recommended.

6.6.3 Top spit recommendations

- It is advisable not to harvest down to fen peat as restoration to a bog ecosystem will take substantially longer, and a source for fen top spit is not always in the vicinity of the harvested site.

- Rewetting measures must be begun before top spit is applied to the site. Adequate moisture levels are needed for good vegetation growth. Water levels should be close to the peat surface during the growing season.

- Areas with inadequate moisture levels for top spit growth may be better suited for peatland trees and shrubs. These trees and shrubs may help to ameliorate the micro-environment around them. Thus in time when moisture levels are sufficient and top spit may be spread, top spit vegetation growth may benefit from the established companion plants.

- To minimize the damage on natural peatlands, restoration plans can include gathering bog top spit from areas which are designated for peat harvesting.

- If fen top spit is needed, or no further harvestable bog top spit is available, care should be taken to limit damage on natural peatlands which serve as source sites. Limiting the depth of top spit removed from the natural area to 10 cm will help the source site to recover, and still provide viable top spit for the harvested site (Campeau and Rochefort 1996, Quinty and Rochefort 1997).

- Spring application appears to be the best time for application of the top spit for revegetation cover, while a summer application treatment had higher species richness and proportion of peatland plants. The differences in time from collection and application for the two treatments (5 mo compared to 1 d), may have affected top spit viability. Thus a combination of the results is advised: early spring application of top spit, with application directly following collection. Spring is also the best time to gather the top spit material from the source site. To remove a thin layer of top spit, the source area can be scraped in the early spring with a cat, bulldozer, or similar machine when the frost level is approximately 10 cm from the surface.

- With most of the frost still in the ground, heavy machinery will have less impact on the source site. This is especially beneficial if the source site is in a nonharvestable area.

- Once the top spit is collected, processing and application on the harvested site should follow immediately to avoid desiccation of the material.

- Since a thinner layer of top spit (1-2 cm thick) had better revegetation cover and number of species than a thicker layer (2-4 cm thick), top spit should be applied in a thin layer. Raking by hand may be necessary if spreading with a manure spreader does not achieve an evenly thin application.

- If only a thin layer of the harvested site was removed, chemical conditions may still be similar to the original bog conditions, and bog top spit would probably be successful in the rewetted site. If chemical characteristics are more fen-like, the use of fen top spit is advised.

- As the timing of top spit collection and application is vital for revegetation success, and as source sites for top spit are not always available, more research should be conducted into methods of farming *Sphagnum* and top spit material.

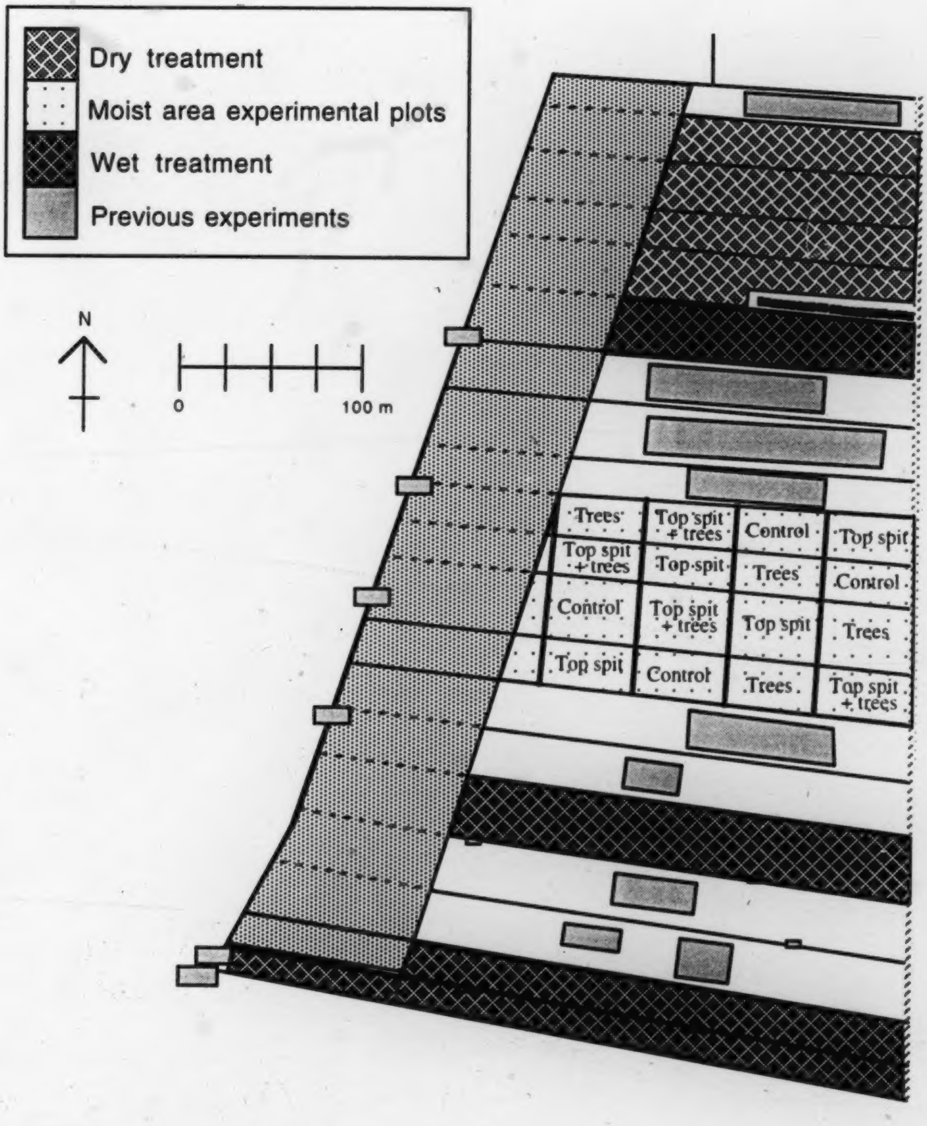
- These gathering and application of top spit techniques depend on freezing temperatures and frost levels. In areas outside Canada, these techniques may need some adaptations as local climates dictate.

6.7 Restoration costs

Suggestions have been made that a cost analysis of peatland restoration could be included in this dissertation. Some preliminary estimates have been made by Line Rochefort's research group. These estimates have been deemed unrealistic by industry members, and the author was advised not to attempt a cost analysis (L. Rochefort, personal communication 1998). More work is needed to bring down the costs of restoration, and scientists need to collaborate with civil engineers to draw up more realistic estimates.

6.8 Closing remarks

This research has furthered the field of peatland restoration in Canada. We have come a long way, starting with the dry, dusty, barren site and ending with a site which supports *Sphagnum* moss and peatland vegetation. When we began, we were uncertain whether the site could adequately rewet for vegetation growth within a decade. Although much has been learned through this thesis project, there are still many questions to answer, and we look forward as scientists and industry work together toward our goal of the restoration of harvested peatlands.


Dry treatment
Moist area experimental plots
Wet treatment
Previous experiments
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100 m
Trees
Top spit + trees
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Control
Top spit + trees
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Trees
Top spit
Control
Trees
Top spit + trees

Figure 6-1. Restoration plan map for the Seba Beach harvested site.

6.9 References

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Appendix 1 Water chemistry detailed methods

A-1.1 New Brunswick - Maisonnette

To collect water samples, a series of 19 random pits (40 cm X 40 cm X ~40 cm deep) were dug on the harvested site along 3 harvested bays. Four pits were also dug in the natural, nonharvested area. Water samples were collected from both sites were collected in October 1992 and May 1993. Samples were filtered using a 0.45 µm cellulose acetate filter prior to analyses. Water samples were measured for pH and conductivity using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), methods #423, and #205. Conductivity values were corrected for temperature and hydrogen ions (Sjörs 1952). Water samples were stored in 1-L Nalgene polyethylene bottles for Na+, K+, Ca2+, Mg2+, Cl-, SO42-, total phosphorus (TP), and NO3--N analyses. Water samples for NH4+-N analyses were stored in 250 mL polyethylene bottles. Samples for Na+, K+, Ca2+, and Mg2+ were analyzed on an atomic absorption spectrometer (Varian 1475). Sodium was measured following the methods of the Association of Official Analytical Chemists (AOAC) (1990), method #973.54, spectrophotometric method with atomic absorption. Potassium was measured following the method #973.53 (AOAC 1990), spectrophotometric method with atomic absorption. Magnesium was measured following the method #974.27 (AOAC 1990), spectrophotometric method with atomic absorption. Calcium was measured following the method #303A (APHA et al. 1985), spectrophotometric method with atomic absorption. Analyses of Cl-, SO42-, and nitrate were conducted by ion chromatography with a Waters chromatographic system. Samples for TP were analyzed colormetrically on a UV/vis LKB Urtrospec II (AOAC 1990, method #973.55, photometric method). Ammonium samples were analyzed by steam distillation with a Kjeltec 1002 Distillation System, following AOAC (1990) method #973.49, titrimetric potentiometric method.

Surface water samples were analyzed by the Peat Research and Development Centre in Shippagan, New Brunswick.

A-1.2 Eastern Québec - Rivière-Ouelle

Water samples were collected from 3 pits (40 cm X 40 cm X 1 m deep) along a transect in the harvested site and from one pit in the natural area. Samples were collected from both sites in August, 1993. Samples were filtered using a 0.45 µm cellulose acetate filter prior to analyses. Water samples were measured for pH and conductivity using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), methods #423, and #205. Conductivity values were corrected for temperature and hydrogen ions (Sjörs 1952). Water samples were stored in 1-L Nalgene polyethylene bottles for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total phosphorus (TP), and NO_3^--N analyses. Water samples for NH_4^+-N analyses were stored in 250 mL polyethylene bottles. Samples for Na^+, K^+, Ca^{2+}, and Mg^{2+} were analyzed on an atomic absorption spectrometer (Varian 1475). Sodium was measured following the methods of the Association of Official Analytical Chemists (AOAC) (1990), method #973.54, spectrophotometric method with atomic absorption. Potassium was measured following the method #973.53 (AOAC 1990), spectrophotometric method with atomic absorption. Magnesium was measured following the method #974.27 (AOAC 1990), spectrophotometric method with atomic absorption. Calcium was measured following the method #303A (APHA et al. 1985), spectrophotometric method with atomic absorption. Analyses of Cl^-, SO_4^{2-}, and nitrate were conducted by ion chromatography with a Waters chromatographic system. Samples for TP were analyzed colormetrically on a UV/vis LKB Urtrospec II (AOAC 1990, method #973.55, photometric method). Ammonium samples were analyzed by steam distillation with a Kjeltec 1002 Distillation System, following AOAC (1990) method #973.49, titrimetric potentiometric method.

Surface water samples were analyzed by the Peat Research and Development Centre in Shippagan, New Brunswick.

A-1.3 Central Québec - Sainte-Marguerite-Marie

Water samples were collected in August and September, 1992 from natural depressions and from the adjacent ditches along three harvested bays. The bays were 400 m long, and were divided into 3 equal sections (approximately 130 m long) for sampling. In 1993, 10 additional water pits were randomly dug in the harvested area, and one water pit was dug in the natural area. The pits were 30-50 cm in diameter, and were dug down to the water table. Water samples were collected in July, August, and October, 1993 for partial or full analyses. Samples were filtered using a 0.45 μm cellulose acetate filter prior to analyses. Water samples were measured for pH and conductivity using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), methods #423, and #205. Conductivity values were corrected for temperature and hydrogen ions (Sjörs 1952). Water samples were stored in 1-L Nalgene polyethylene bottles for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total phosphorus (TP), and NO_3^--N analyses. Water samples for NH_4^+-N analyses were stored in 250 mL polyethylene bottles. Samples for Na^+, K^+, Ca^{2+}, and Mg^{2+} were analyzed on an atomic absorption spectrometer (Varian 1475). In 1992, samples were analyzed using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), method #303A. In 1993, samples were analyzed using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), (method #303A for Ca^{2+}), or following the methods of the Association of Official Analytical Chemists (AOAC) (1990), (method #973.54, spectrophotometric method with atomic absorption for Na^+, method #973.53, spectrophotometric method with atomic absorption for K^+, and method

#974.27, spectrophotometric method with atomic absorption for Mg^{2+}). Analyses of Cl^-, SO_4^{2-}, and nitrate were conducted by ion chromatography with a Waters chromatographic system (APHA et al. 1985, method #429). Samples for TP were analyzed colormetrically on a UV/vis LKB Urtrospec II (for 1992 samples, APHA et al. 1985, method #424CIII; for 1993 samples, AOAC 1990, method #973.55, photometric method). Ammonium samples were analyzed by steam distillation with a Kjeltec 1002 Distillation System (for 1992 samples, APHA et al. 1985, method #417A and D; for 1993 samples, AOAC 1990, method #973.49, titrimetric potentiometric method). Surface water samples were analyzed by the Centre de Recherches minérales, Ministère de l'Énergie et des Ressources (Gouvernement du Québec), in Sainte-Foy, Québec in 1992, and by the Peat Research and Development Centre in Shippagan, New Brunswick in 1993.

A-1.4 Alberta - Seba Beach

Surface water samples were obtained from pools, ditches, or from within water level wells. On the harvested site, ditches were first sampled, randomly, but approximately equally along the western quarter. With the installation of water level wells (see Figure 4-1), additional water samples were obtained from the surface water within the well, either by immersing the sample bottle in the well, or by drawing water up by suction with a syringe and rubber hose. In the natural area, water samples were obtained within the well, and from nearby shallow pools. Water samples were collected in July and August 1991, June and August 1992, and August 1993. Sample size for ditch water samples ranged from 2-15 from 1991-1993 (Table 3-1 indicates yearly n sizes). In 1993, 10 water samples were collected from the wells in the harvested area, and 2 water samples were collected in the natural.

Surface water pH was measured digitally in the field or in the lab (Stainton et al. 1977 methods). Surface water samples were measured for conductivity values with corrections for temperature at 20 °C and hydrogen ions (Sjörs 1952). Surface water nutrients were analyzed by the Department of Zoology at the University of Alberta. Water samples were stored in 1-L Nalgene polyethylene bottles for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total phosphorus (TP), and NO_3^--N analyses. Water samples for $NH4^+$-N analyses were stored in 250 mL polystyrene flasks. Samples for Na^+, K^+, Ca^{2+}, and Mg^{2+} were filtered through a prewashed Whatman GF/C filter, stored at 4 °C, and analyzed on an atomic absorption spectrometer (Perken-Elmer, model 3300). Analyses of Cl^- and SO_4^{2-} were conducted by ion chromatography with a Waters chromatographic system. Samples for TP were filtered under low pressure (-50 kPa), through a 250-µm Nitex net and transferred to culture tubes (Prepas and Rigler 1982; modified from Menzel and Corwin 1965). These samples were analyzed colormetrically on a Milton Roy Spectronic Spectrometer. After filtration through a prewashed 0.45-µm HAWP Millipore membrane filter, nitrate was determined on the technicon by the cadmium-copper reduction method of Stainton et al. (1977). Ammonium samples were analyzed on the technicon by Solórzano's (1969) phenolhypochlorite method as modified by Prepas and Trew (1983).

A-1.5 References

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Appendix 2.

Water chemistry methods summary table

	New Brunswick 1992/1993	eastern Québec 1993	central Québec 1992/1993	Alberta 1991/1992/1993
pH	Method #423 (APHA et al. 1985)	Method #423 (APHA et al. 1985)	Method #423 (APHA et al. 1985)	Stainton et al. (1977)
Corrected Conductivity	Method #205, (APHA et al. 1985), corrected for temperature and pH (Sjörs 1952)	Method #205, (APHA et al. 1985), corrected for temperature and pH (Sjörs 1952)	Method #205, (APHA et al. 1985), corrected for temperature and pH (Sjörs 1952)	(Stainton et al. 1977), corrected for temperature and pH (Sjörs 1952)
P total	Photometric method #973.55 (AOAC 1990)	Photometric method #973.55 (AOAC 1990)	Photometric method #424CIII (APHA et al. 1985)	Photometric, methods (Prepas and Rigler 1982)
NH_4^+-N	Steam distillation, method #973.49, titrimetric determination (AOAC 1990)	Steam distillation, method #973.49, titrimetric determination (AOAC 1990)	Steam distillation, method #417A and D (APHA et al. 1985)	Technicon, Solórzano's (1969) phenolhypochlorite method, modified by Prepas and Trew (1983)
NO_3^--N	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Technicon, Cadmium-copper reduction method (Stainton et al. 1977)
Na^+	Atomic Absorption, method #973.54 (AOAC 1990)	Atomic Absorption, method #973.54 (AOAC 1990)	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)
K^+	Atomic Absorption, method #973.53 (AOAC 1990)	Atomic Absorption, method #973.53 (AOAC 1990)	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)
Ca^{2+}	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)
Mg^{2+}	Atomic Absorption, method #974.27 (AOAC 1990)	Atomic Absorption, method #974.27 (AOAC 1990)	Atomic Absorption, method #303A (APHA et al. 1985)	Atomic Absorption, method #303A (APHA et al. 1985)
SO_4^{2-}	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system
Cl^-	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system	Ion chromatography, Waters chromatographic system

Appendix 3 Peat chemistry detailed methods

A-3.1 New Brunswick - Maisonnette

Six peat samples were collected randomly throughout the harvested site. Samples were collected by hand from a depth of 1-5 cm from the peat surface, in August 1993. Samples were stored in polyethylene bags at a cool temperature until analysis.

For peat pH and conductivity analyses, fresh peat samples were saturated with distilled water, filtered on a Whatman #1 filter and measurements were obtained from the filtrate using Standard Methods for the Examination of Water and Wastewater (APHA et al. 1985), methods #423 and #205. Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs (1952). Steam distillation procedures (AOAC 1990, method #973.49, titrimetric determination) were used with 10 g of peat in 100 mL double distilled water to determine levels of NH_4-N.

A-3.2 Eastern Québec - Rivière-Ouelle

To sample the two harvested bays at the Rivière-Ouelle, each bay was divided in half, and peat samples were randomly collected from each section. The peat samples were collected from a depth of 1-5 cm with a small shovel. One sample was collected by shovel from the natural area, from a depth of 10-15 cm. Samples were collected in August 1993, and were stored in polyethylene bags at a cool temperature until analysis.

Peat pH was analyzed using 3 g of air dried peat with 50 mL of 0.01 M $CaCl_2$ using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), method #423. Peat electrical conductivity analyses were conducted using a 1:10 ratio of fresh peat and distilled water (APHA et al. 1985, method

#205). Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs (1952).

Surface peat samples were analyzed for Ca, Mg, Na, and K by saturating the peat with distilled water, and analyzing the filtrate by atomic absorption (for Mg, AOAC method #974.27; for Ca, APHA et al. method #303A; for Na, AOAC method #973.54; for K, AOAC method #973.53).

A-3.3 Central Québec - Sainte-Marguerite-Marie

Surface peat samples (1-5 cm deep) were collected by hand in May, 1992 from three harvested bays. The bays were 400 m long, and were divided into 3 sections for sampling, with 3 peat samples collected by hand from each section. In August, 1993, 3 peat samples were collected from the bays, with 4 additional samples collected from a neighbouring bay, and one peat sample was collected in the natural area (10-15 cm deep). Full or partial analyses were conducted with the peat samples.

Peat pH was analyzed using 3 g of air dried peat with 50 mL of 0.01 M $CaCl_2$ using Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1985), methods #423. Peat electrical conductivity analyses were conducted using a 1:10 ratio of fresh peat and distilled water (APHA et al. 1985, method #205). Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs (1952).

Surface peat samples were analyzed for Ca, Mg, Na, and K by one of two methods: 1/ displacing the cations by agitating the sample in a solution of 1N ammonium acetate (CH_3COONH_4) at pH 7 and then analyzing the filtrate by atomic absorption spectrophotometry (1992 samples) (De Blois 1991, pp. 347-351), or 2/ saturating the peat with distilled water, and analyzing the filtrate by atomic absorption (for Mg, AOAC

(1990) method #974.27; for Ca, APHA et al. (1985) method #303A; for Na, AOAC (1990) method #973.54; for K, AOAC (1990) method #973.53) (1993 samples).

Steam distillation procedures were used with 10 g of peat in 100 mL double distilled water to determine levels of NH_4-N (for 1992 samples, APHA et al. (1985) methods #417A and D; for 1993 samples, AOAC (1990) method #973.49, titrimetric determination).

Total sulfur was analyzed by oxidizing sulfur into SO_2 and measuring this gas in a LECO S analyzer (De Blois 1991, pp. 229-230).

Peat samples were analyzed by the Centre de Recherches minérales, Ministère de l'Énergie et des Ressources (Gouvernement du Québec), in Sainte-Foy, Québec in 1992, and by the Peat Research and Development Centre in Shippagan, New Brunswick in 1993.

A-3.4 Alberta - Seba Beach

Peat samples were collected from 0-5 cm profiles from the harvested peat surfaces and from 1-5 cm profiles in the natural area, using a TJ-10.5 corer, a tomato juice can with one edge cut to form a handle, and the other cut and filed to form a sharp cutting edge, with an opening diameter of 10.5 cm. In the natural area, random samples were gathered within the vicinity of the natural area well (n=2, with the occasional exception, see Table 3-2). In the harvested area, peat sampling varied between years. In July 1991, the harvested field was sampled for peat pH and conductivity by dividing the field into 70 m sections along the bays, and randomly collecting samples within each section (n=86). Additional samples were collected in September 1991 for further pH and conductivity testing (n=23). In July and August 1992, the sampling design was altered to reduce the sample size for financial considerations. Each harvesting bay was divided in half, and was randomly sampled within each section (n=40). Peat samples were either fully or partially analyzed (Table 3-2 indicates the size n for each chemical component). In September 1993, peat samples collected along the western quarter were randomly placed by selected revegetation plots, while the rest of the site was divided into four sections and randomly sampled within each section (n=40). Samples were stored in polyethylene bags at a cool temperature until analysis.

Peat pH was analyzed using a 1:2 ratio of fresh peat and double distilled water using methods from the Department of Soil Science at the University of Alberta (1990). Peat conductivity analyses were conducted using the same ratios. Peat conductivity measurements were corrected for temperature to 20 °C and for pH according to Sjörs (1952). Peat pH and conductivity samples were measured by the author with the aid of various assistants.

Surface peat samples were analyzed for the elements Ca, K, Mg, Na, P, and S by dry ashing methods. Peat samples were ovendried at 60 °C, and then ground to 1/2 mm or less. Subsamples 0.3-0.4 g were dry ashed at 470 °C, and acid digested with 6 mL 1.5 N HCl and 1 mL concentrated HNO_3. Digested samples were filtered through Whatman #42 filter paper and analyzed by inductively coupled plasma spectrophotometry. Available nitrate and ammonia were extracted by using 1:20 ratio of air-dry ground peat and 2N KCl, mechanically shaken for 30 minutes and analyzing the filtrate using a technicon autoanalyser and the Industrial Methods 158-71 W/B, December 1972, and 696-82W, April 1983, respectively. Samples were prepared by the author with the aid of various assistants, and analyzed by the Department of Zoology at the University of Alberta (available NO_3-N, and available NH_4-N samples) and by Forestry Canada, Northern Forestry Centre (Ca, K, Mg, Na, P, and S samples).

A-3.5 References

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Appendix 4.

Peat chemistry methods summary

	pH	Corrected Conductivity	P total	NH4-N	NO3-N
New Brunswick 1993	method #423 using saturated media filtrate (APHA et al. 1985)	method #205 using saturated media filtrate (APHA et al. 1985)		Steam distillation, 10 g peat with 100 mL ddw, method #973.49, tiremitric determination (AOAC 1990)	
eastern Québec 1993	3 g dried peat with 50 mL 0.01 M $CaCl_2$, method #423 (APHA et al. 1985)	1:10, fresh peat:distilled water using method #205 (APHA et al. 1985)			
central Québec 1992/1993	3 g dried peat with 50 mL 0.01 M $CaCl_2$, method #423 (APHA et al. 1985)	1:10, fresh peat:distilled water using method #205 (APHA et al. 1985)		Steam distillation, 10 g peat with 100 mL ddw, method #417A + D (1992 values) and #973.49, tiremetric determination (1993 values) (APHA et al. 1985, AOAC 1990)	
Alberta 1991/1992/1993	1:2, fresh peat:double distilled water: (Dept. Soil Science, UofA 1990)	1:2, fresh peat:double distilled water: (Dept. Soil Science, UofA 1990)	Dry ashing, ICP-AES	1:20 air-dry ground peat:2N KCl, Technicon autoanalyser (Industrial Methods 696-82W, April 1983)	1:20 air-dry ground peat:2N KCl, Technicon autoanalyser (Industrial Methods 158-71 W/B, Dec. 1972)

Appendix 4 continued.

Peat chemistry methods summary

	Na	K	Ca	Mg	S
New Brunswick 1993					
eastern Québec 1993	Atomic Absorption, method #973.54 using saturated media filtrate (AOAC 1990)	Atomic Absorption, method #973.53 using saturated media filtrate (AOAC 1990)	Atomic Absorption, method #303A using saturated media filtrate (APHA et al. 1985)	Atomic Absorption, method #974.27 using saturated media filtrate (AOAC 1990)	
central Québec 1992/1993	Atomic Absorption, using filtrate from ammonium acetate solution (1992 values), or method #973.54 using saturated media filtrate (1993 values) (APHA et al. 1985, AOAC 1990)	Atomic Absorption, using filtrate from ammonium acetate solution (1992 values), or method #973.53 using saturated media filtrate (1993 values) (APHA et al. 1985, AOAC 1990)	Atomic Absorption, using filtrate from ammonium acetate solution (1992 values), or method #303A using saturated media filtrate (1993 values) (APHA et al. 1985)	Atomic Absorption, using filtrate from ammonium acetate solution (1992 values), or method #974.27 using saturated media filtrate (1993 values) (APHA et al. 1985, AOAC 1990)	LECO S analyser (1992 values) (De Blois 1991)
Alberta 1991/1992/1993	Dry ashing, ICP-AES	Dry ashing, ICP-AES	Dry ashing, ICP-AES	Dry ashing, ICP-AES	Dry ashing, ICP-AES

Appendix 5 Discussion on how differing chemistry methods may have affected the results

A-5.1 Differing water chemistry methods

The water chemistry methods from the four sites in Chapter 2 had few differences between sites. Conductivity and pH were measured with similar methods. The cations Ca^{2+}, K^+, Mg^+, and Na^+ were measured by standard atomic absorption methods. The anions Cl^-, SO_4^{2-} were measured by ion chromatography. Total phosphorus was measured by photometric methods. The only chemical analyses with differing methods were NO_3^--N and NH_4^+-N analyses (Appendix 2).

The two methods used for the NO_3^--N analyses were ion chromatography and the cadmium-copper reduction method with the technicon (Stainton et al. 1977). Although these methods are different, they are recognized to give similar results (Brian Rothwell, University of Alberta, Zoology lab, personal communication; Mike Stainton, Freshwater Institute, University of Manitoba, personal communication). Round robin examinations have shown that both technicon and ion chromatography methods produce similar results (Alkema 1995).

For NH_4^+-N analyses, eastern water samples had the ammonia separated out by distilling the water samples with a borate buffer at pH 9.5, and then measuring the ammonia concentration by titration (AOAC 1990, method #973.49; APHA et al. 1985, methods #417A and D). The operating range for this method is 1-25 mg N/L, and as some of the eastern water samples had ammonia levels below this limit, a more diluted acid was used in the titration step for these samples (Jean-Yves Daigle, Peat Research and Development Centre, New Brunswick, personal communication). For the western water samples, the phenolhypochlorite method was used (Solórzano 1969, modified by Prepas and Trew 1983). In this method, ammonia reacts with alkaline phenol and sodium hypochlorite at pH 9.8-10.4. An indophenol blue colour is formed whose intensity is directly related to the concentration of ammonia, which is then measured automatically by a technicon autoanalyzer. No extra distillation or extraction steps are needed as citrate is added to complex with magnesium and calcium, which may otherwise interfere with the phenolhypochlorite reaction (Solórzano 1969). The NH_4^+-N concentrations in the Alberta water samples were within the detection limits, 2.8-140 µg N/L, for this method. It is unclear whether boron (used the distillation methods) can drive ammonia off the exchange sites in proportion to phenolhypochlorite, but it is assumed to be equal.

Although most of the water chemistry methods were similar, and therefore, the results should be comparable, a few changes would have improved this study. One improvement would have been to have a single lab conduct all the analyses. The use of a single lab would have excluded any differences in methods and techniques. As distance was a factor between the sites, and therefore time to sample analysis would have been extended if a single lab was used, another possible improvement would have been to have local labs use the identical methods. In addition, identical samples could have been analyzed by all the labs involved to confirm comparability, as in an informal round robin examination. Another check could have been to inspect how the labs fared in a formal round robin examination, in which the results from numerous different labs on the same series of unknown samples are compared and graded by an outside adjudicator.

Regrettably, the idea for the chemical comparisons of these sites was developed after all the chemical analyses were completed. Additional samples were not sent out to the different labs for comparison analyses, due to time constraints. A check of comparability could not be done post-analysis by checking formal round robin examinations, as the labs involved did not participate in the same round robins. Although the different labs received good grades by their differing agencies (National Water Research Institute for the University of Alberta lab; Canadian Food Inspection Agency and the Canadian Association of Environmental Analytical Laboratories for the Peat Research and

Development Centre; and Standards Council of Canada for the Centre de Recherches minérales, Ministère de l'Énergie et des Ressources (Gouvernement du Québec)), comparing the results between labs should be done cautiously, and the proposed improvements should be considered for future experiments.

A-5.2 Differing peat chemistry methods

The four sites in Chapter 2 had a number of differing peat chemistry methods which may have affected the comparability of the results (Appendix 4). The improvements previously mentioned in Appendix 5.1 would also have improved the peat chemistry comparisons.

Peat pH was measured in three different ways: 1/ by using a 1:2 ratio of fresh peat and double distilled water using methods from the Department of Soil Science at the University of Alberta (1990), (Alberta samples) 2/ by saturating the samples with distilled water, filtering the slurry with a Whatman #1 filter, and measuring pH on the filtrate (New Brunswick samples) or 3/ by measuring mixtures of 3 g of air dried peat with 50 mL of 0.01 M $CaCl_2$, (Québec samples). Thus these methods differ in soil/solution ratios and differ in type of solutions. Day et al. (1979) has stated that pH values obtained in 0.01 M calcium chloride solution would usually run 0.5-0.8 pH unit lower than values obtained in water, due to the release of more hydrogen ions by cation exchange. To express the conversion between pH values derived from water and calcium chloride solutions with the range of low to near neutral pH values, Ahern et al. (1995) formulated the equation $pH_{Ca}=0.590pH_W+0.0249pH^2{}_W+0.6848$. Experimental results showed that this formula was unsuitable for converting the pH values derived from the methods used in Chapter 2 (see Appendix 6 for more details). Instead, the average differences in the water and $CaCl_2$ pH values were calculated. These average differences, 0.9 units lower for the saturated method, and 0.8 units lower for the 1:2 ratio method, were used to convert the New Brunswick and Alberta pH values. The New Brunswick harvested site would be reduced from 3.6 (3.4-3.9) pH_W to 2.7 (2.5-3.0) pH_{Ca}, the Alberta natural site would be reduced from 4.2 to 3.4, and at the Alberta harvested site from 4.4 (3.8-8.0) pH_W to 3.6 (3.0-7.2) pH_{Ca}. With these calculated values, the Alberta harvested site still had higher pH values than the other three harvested sites.

Peat conductivity was measured in three different ways: 1/ by using a 1:2 ratio of fresh peat and double distilled water using methods from the Department of Soil Science at the University of Alberta (1990), (Alberta samples) 2/ by using a 1:10 ratio of fresh peat and distilled water, (Québec samples) or 3/ by saturating the samples with distilled water, filtering the slurry with a Whatman #1 filter, and measuring pH on the filtrate (New Brunswick samples). Peat conductivity measurements were corrected for pH and temperature to 20 °C according to Sjörs (1952). As electrical conductivity is proportional to the amount of dissolved salts present, the varying ratios of peat:water would affect the results of the peat conductivity analyses (Day et al. 1979). To compare the three methods, 10 g samples were mixed with varying ratios of water, and analyzed for conductivity levels (See Appendix 7). In this experiment the 1:2 ratio method and the saturated peat method gave similar results, and the 1:10 ratio method gave conductivity values approximately four times lower in value, with less variation.

To equalize the conductivity values measured by various methods, the values obtained by the saturated peat method and the 1:2 ratio method were divided by four. With these corrections, the New Brunswick natural area peat corrected conductivity value remains at 0 µS/cm, the Alberta natural area peat corrected conductivity is 2.5 µS/cm, and the harvested area is reduced to a mean of 16 µS/cm, with a range of 0-150 µS/cm. These reductions do not significantly change the results or discussion of Chapter 2.

Available ammonia was extracted by one of two ways: 1/ by using 1:20 ratio of air-dry ground peat and 2N KCl, mechanically shaken for 30 minutes and analyzing the filtrate using a technicon autoanalyser and the Industrial Methods 696-82W, April 1983, (Alberta samples) or 2/ by steam distillation of 10 g samples placed in 100 mL of double distilled water (APHA et al. (1985) methods #417A and D; AOAC (1990) method #973.49, titrimetric determination) (New Brunswick and central Québec samples). With steam distillation, the ammonia is separated out by distilling the peat solution samples with a borate buffer at pH 9.5, and then measuring the ammonia concentration by titration. It is assumed that both boron and potassium exchange ammonia equally.

Surface peat samples were analyzed for the elements Mg, Na, K, and Ca by one of three ways: 1/ by dry ashing and acid digestion methods: Peat samples were ovendried at 60 °C, and then ground to 1/2 mm or less. Subsamples 0.3-0.4 g were dry ashed at 470 °C, and acid digested with 6 mL 1.5 N HCl and 1 mL concentrated HNO_3. Digested samples were filtered through Whatman #42 filter paper and analyzed by inductively coupled plasma spectrophotometry, (Alberta samples) 2/ by displacing the cations by agitating the sample in a solution of 1N ammonium acetate (CH_3COONH_4) at pH 7 and then analyzing the filtrate by atomic absorption spectrophotometry (De Blois 1991, pp. 347-351), (central Québec, 1992 samples) or 3/ by saturating the peat with distilled water and measuring the filtrate, using atomic absorption spectrophotometry (AOAC 1990, methods #974.27, #973.54, and #973.53; APHA et al. 1985, method #303A) (central Québec, 1993 samples, eastern Québec samples).

These three methods will not give directly comparable results. Dry ashing and acid digestion methods measure the total elemental content in the peat, while saturating the samples with ammonium acetate or water causes the exchangeable cations to be released into solution.

Pätilä (1990) investigated exchangeable cation concentrations in relation to element levels in peat samples, by extracting exchangeable cations using 1 M ammonium acetate (NH_4OAc at pH 7), and comparing the results of dry ashing, acid digestion in HCl and analysis by inductively coupled plasma spectrophotometry. Pätilä found a high correlation between exchangeable bases and elemental content. The ratio of exchangeable:total bases was 0.97:1 for K, 0.73:1 for Mg, and 0.52:1 for Ca. Sodium levels were low in the Finnish peats, and no ratio was calculated for Na.

These ratios were used to reduce the Alberta peat chemistry results from total elemental levels down to exchangeable base levels. In the natural area, mean annual level (and range) for exchangeable bases was calculated at 234 (111-357) mg/kg for K, 625 (515-734) mg/kg for Mg, and 3243 (2920-3565) mg/kg for Ca. In the harvested area, mean annual level (and range) for exchangeable bases was calculated at 288 (55-3003) mg/kg for K, 829 (297-2386) mg/kg for Mg, and 3865 (1176-8434) mg/kg for Ca.

As the exchangeable:total bases ratio is close to 1 for K, the comparable numbers are virtually unchanged. Although Alberta magnesium values decreased with these calculations, no new trends were visible. The calculated exchangeable calcium values for Alberta were approximately half of the former levels, yet even at these reduced levels the Alberta site had the highest Ca concentrations. As an exchangeable:total bases ratio for Na is not known, it is unclear how the high Na concentrations at the Alberta site truly compare to the eastern sites. Perhaps the maritime influence of high Na levels in the eastern sites would have been apparent in the harvested peat if exchangeable Na had been measured at the Alberta site.

As mentioned above, both the ammonium acetate and water saturated peat methods measure the exchangeable cations released into solution. Although no literature was found directly comparing these methods, Tummavuori et al. (1981) found that ammonium acetate gave 0.3 to 15 times higher results compared to water methods (using different peat:solution proportions, and using 0.5 M ammonium acetate). As the samples from central Québec were analyzed by the ammonium acetate methods in 1992 and water saturated peat methods in 1993, these values can be examined and compared (see Appendix 8). Unexpectedly, the 1992 values are not consistently higher than the 1993 values.

Total S in the surface peat was measured in one of two ways: 1/ by dry ashing and acid digestion methods: Peat samples were ovendried at 60 °C, and then ground to 1/2 mm or less. Subsamples 0.3-0.4 g were dry ashed at 470 °C, and acid digested with 6 mL 1.5 N HCl and 1 mL concentrated HNO_3. Digested samples were filtered through Whatman #42 filter paper and analyzed by inductively coupled plasma spectrophotometry, (Alberta samples) or 2/ by oxidizing sulfur into SO_2 and measuring this gas in a LECO S analyzer by infra-red detection (De Blois 1991, pp. 229-230) (central Québec, 1992 samples). Although, LECO S analyzer methods in the past have been criticized as being imprecise (Tabatabai 1982), older methods were used to measure sulfate by titration. Using the newer methods, sulfur measurements at the Centre de Recherches minérales, Ministère de l'Énergie et des Ressources (Gouvernement du Québec) were within the specifications of the Standards Council of Canada. No literature was found comparing the dry ashing/acid digestion methods and LECO S analyzer methods. Central Québec and Alberta sulfur levels were not compared in Chapter 2.

In these ways the differing methods may have affected the comparability of the peat chemistry results discussed in Chapter 2. Although some site results might not be directly comparable due to the variation in methods, the discussion in Chapter 2 focused on how harvested and neighbouring natural peatlands compared. Thus, the possible differences were minimized.

A-5.3 References

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Appendix 6 Experiment comparing the effect of differing measuring methods on peat pH

A-6.1 Introduction

As three different methods were used to calculate peat pH values in Chapter 2, a series of peat samples was analyzed using these methods to observe for possible effects and to determine if conversion formulas could be made.

A-6.2 Methods

To compare a range of peat materials, five samples were chosen for this experiment. The first three samples were from the surface layer (0-5 cm deep) of the Seba Beach harvested site, collected on July 13, 1995. One sample was randomly chosen from a drier area, and two samples were randomly chosen from saturated areas. These frozen peat samples were defrosted prior to the start of the experiment. The two remaining samples composed of surface live moss, collected from a natural peatland at Clear Lake, Alberta (54°14'N, 114°58'W), in the summer of 1995. *Sphagnum fuscum* and *Sphagnum angustifolium* were the two moss species.

This experiment was divided into two components: water and calcium chloride methods. For the water methods, three subsamples of approximately 10 g was measured into 100 mL acid washed jars from each of the five samples, for a total number of 30. For the 1:2 ratio of fresh peat:double distilled water, methods from the Department of Soil Science at the University of Alberta (1990) were used. To the 10 g subsample of fresh peat, 20 mL of double distilled water was added. If the subsample absorbed all the water, as in samples 3 and 4, an additional 20 mL of double distilled water was added. Glass rods were used to stir the mixture periodically for 30 minutes. After a further resting period of 30 minutes, pH and temperature were measured. The mean pH and standard deviation values for the three subsamples were calculated and graphed (Figure A6-1). For the saturated peat methods, varying amounts distilled water, ranging from 5-36 mL, was added to the 10 g fresh peat subsamples. Only enough water was added to saturate the subsamples. Glass rods were used to mix the peat and water. The saturated subsamples stood for 24 hours. Using an 11 cm buchner funnel and 11 cm Whatman #1 filter paper, saturated subsamples were filter by suction into a 25 mL vacuum flask. After the filtrate was transferred into 75 mL acid washed jars, the filtrate was measured for pH and temperature. The mean pH and standard deviation values for the three subsamples were calculated and graphed (Figure A6-1).

For the calcium chloride section of the experiment, subsamples, ranging in fresh weight of 18-108 g, were weighed in weigh boats, and allowed to air dry. Three subsamples of each of the five samples, for a total number of 15, were weighed. From the air dried subsamples, 3 g was placed into 100 mL acid washed jars, and 50 mL of 0.01 M $CaCl_2$ was added. Glass rods were used to mix the peat and solution for 5 seconds, and then the mixture was allowed to rest for 30 minutes. Temperature and pH were measured. The mean pH and standard deviation values for the three subsamples were calculated and graphed (Figure A6-1). For all experimental sections a digital, Fisher Scientific Accumet 1000 Series Handheld pH/mV meter, calibrated with buffer solutions of pH 4 and 7, was used to measure pH and temperature.

A-6.3 Results

The saturated peat method and 1:2 ratio method gave similar results, as the former method had pH values ranging from 3.85-4.71, and the latter method had values ranging from 4.02-4.71. The $CaCl_2$ method had lower pH values, ranging from 2.99-4.01. As illustrated in Figure A6-1, the saturated peat method always had the lowest amount of added solution. On average, the $CaCl_2$ method gave pH values that were 0.9 units lower than the saturated method, and 0.8 units lower than the 1:2 ratio method.

A-6.4 Discussion

The three methods to measure pH vary in soil/solution ratios, in type of solutions, and in fresh or air dried peat. Soil pH, a measure of the hydronium ion activity in the soil solution, can be influenced by these differing methods of measurement.

Differing soil/water ratios can affect the dilution of hydronium ions (Mc Lean 1982). In this experiment, the 1:2 ratio samples had more added water than the saturated peat method, although amounts were similar. The 1:2 ratio method produced similar, but on average slightly lower pH values than the saturated method.

Differing solutions can also affect the dilution of hydronium ions. Day et al. (1979) has stated that pH values obtained in 0.01 M calcium chloride solution will usually run 0.5-0.8 pH unit lower than values obtained in water, due to the release of more hydrogen ions by cation exchange. Ahern et al. (1995) studied pH values derived from water and calcium chloride solutions, and formulated the equation $pH_{Ca}=0.590pH_W+0.0249pH^2{}_W+0.6848$ to express the conversion of pH values with the range of low to near neutral pH values.

Ahern's formula was tested to see if it could be accurately convert the water derived pH values into calcium chloride pH values. The calculated $CaCl_2$ pH values were compared with the actual measured $CaCl_2$ pH values. Although some samples had comparable calculated $CaCl_2$ pH values and actual measured $CaCl_2$ pH values, the formula did not give consistently comparable results. The differences in water/solution ratios and peat freshness in the tested methods (Ahern et al. (1995) used 1:5 air dried soil:solution ratios) make this formula unsuitable.

As differing pH methods make Ahern's formula unsuitable, the average differences in the water and $CaCl_2$ pH values were calculated. These average differences, 0.9 units lower for the saturated method, and 0.8 units lower for the 1:2 ratio method, were used to convert the New Brunswick and Alberta pH values (see Appendix 5-2).

A-6.5 Conclusions

The three peat pH methods used in Chapter 2 , which differed in soil/solution ratios, in type of solutions, and in fresh or air dried peat, gave differing pH measurements. To convert between the three methods the following formulas are proposed:

$pH_{Ca}=pH_{WSat}-0.9$

$pH_{Ca}=pH_{W1:2}-0.8$

A-6.6 References

Ahern, C.R., D.E. Baker, and R.L. Aiken. 1995. Models for relating pH measurements in water and calcium chloride for a wide range of pH, soil types and depths. Plant and Soil 171: 47-52.

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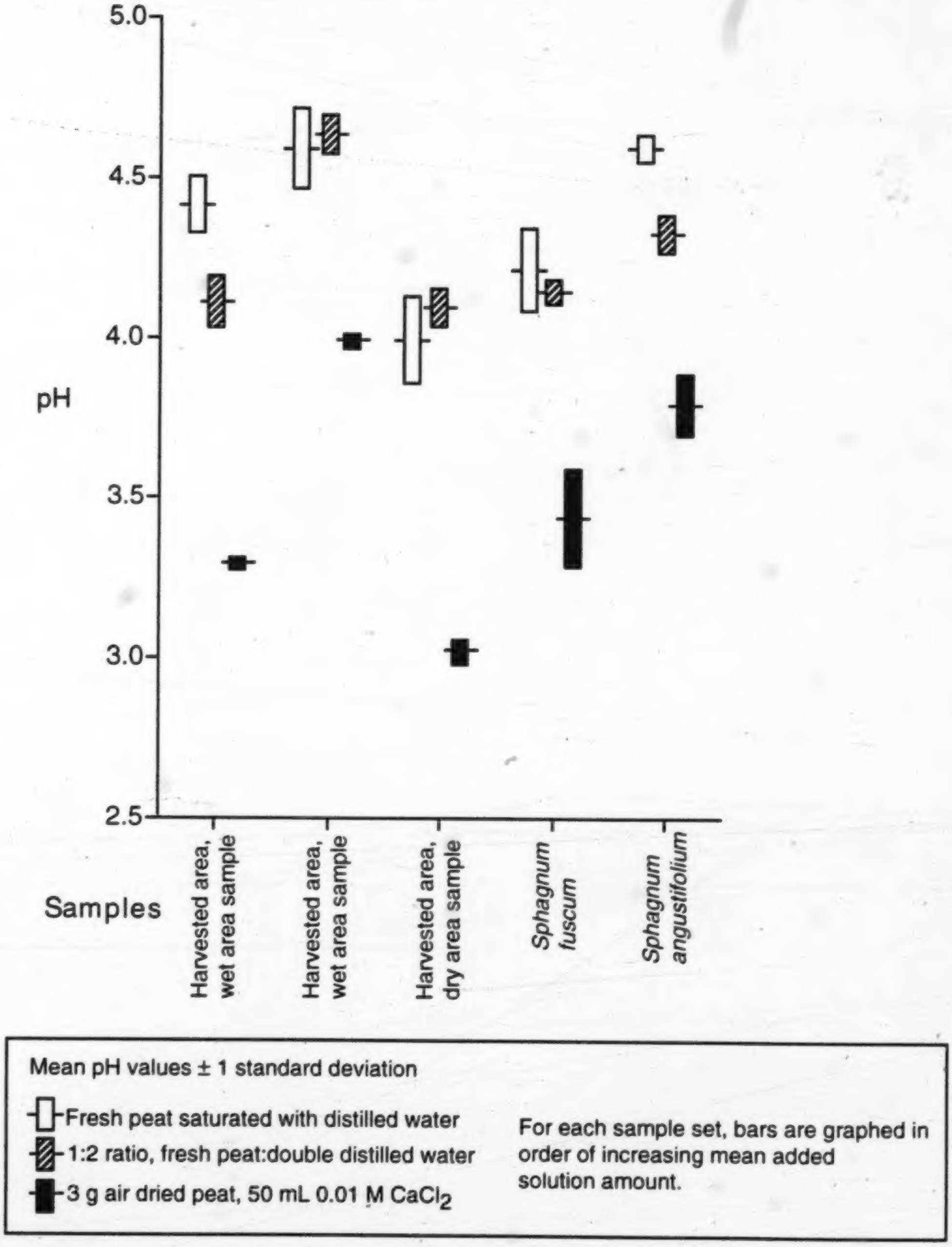

Figure A6-1. Results from three peat pH methods.
Mean pH (± 1 standard deviation) for three methods with five different peat samples. See Appendix 6 for more details.

Appendix 7 Experiment comparing the effect of differing water ratios on peat electrical conductivity

A-7.1 Introduction

As three different methods were used to calculate peat conductivity values in Chapter 2, a series of peat samples was analyzed using these methods to observe for possible effects and to determine if conversion formulas could be made.

A-7.2 Methods

To compare a range of peat materials, five samples were chosen for this experiment. The first three samples were from the surface layer (0-5 cm deep) of the Seba Beach harvested site, collected on July 13, 1995. One sample was randomly chosen from a drier area, and two samples were randomly chosen from saturated areas. These frozen peat samples were defrosted prior to the start of the experiment. The two remaining samples composed of surface live moss, collected from a natural peatland at Clear Lake, Alberta (54°14'N, 114°58'W), in the summer of 1995. *Sphagnum fuscum* and *Sphagnum angustifolium* were the two moss species.

From each of the five samples, three subsamples of approximately 10 g was measured into 100 mL acid washed jars for each of the three methods, for a total number of 45. For the 1:2 ratio of fresh peat:double distilled water, methods from the Department of Soil Science at the University of Alberta (1990) were used. To the 10 g subsample of fresh peat, 20 mL of double distilled water was added. If the subsample absorbed all the water, as in samples 3 and 4, an additional 20 mL of double distilled water was added. Glass rods were used to stir the mixture periodically for 30 minutes. After a further resting period of 30 minutes, the conductivity was measured, followed by the pH and temperature. Conductivity measurements were corrected for pH and temperature according to Sjörs (1952). The mean corrected conductivity and standard deviation values for the three subsamples were calculated and graphed (Figure A7-1).

For the 1:10 ratio of fresh peat:distilled water section of the experiment, 100 mL of distilled water was added to the 10 g fresh peat subsamples. Glass rods were used to stir the mixture periodically for 30 minutes. After a further resting period of 30 minutes, the conductivity was measured, followed by the pH and temperature. Conductivity measurements were corrected for pH and temperature according to Sjörs (1952). The mean corrected conductivity and standard deviation values for the three subsamples were calculated and graphed (Figure A7-1).

In the third experiment section, varying amounts distilled water, ranging from 5-36 mL, was added to the 10 g fresh peat subsamples. Only enough water was added to saturate the subsamples. Glass rods were used to mix the peat and water. The saturated subsamples stood for 24 hours. Using an 11 cm buchner funnel and 11 cm Whatman #1 filter paper, saturated subsamples were filter by suction into a 25 mL vacuum flask. After the filtrate was transferred into 75 mL acid washed jars, the filtrate was measured for conductivity, pH, and temperature. Conductivity measurements were corrected for pH and temperature according to Sjörs (1952). The mean corrected conductivity and standard deviation values for the three subsamples were calculated and graphed (Figure A7-1).

For all experimental sections a digital, Fisher Scientific Accumet 1000 Series Handheld pH/mV meter, calibrated with buffer solutions of pH 4 and 7, was used to measure pH and temperature, and a Bach-Simpson Conductivity Meter was used to measure conductivity.

A-7.3 Results

The 1:2 ratio method and the saturated peat method gave similar results, as the former method had corrected conductivity values ranging from 0-107 μS/cm, and the latter method had values ranging from 0-115 μS/cm. The 1:10 ratio method had lower corrected conductivity values, ranging from 0-27 μS/cm. The 1:10 ratio method also had smaller standard deviations for each sample set (Figure A7-1). In general, lower ratios of fresh peat:water resulted in lower measured corrected conductivity values, although there was some overlap with ± 1 standard deviation. As illustrated in Figure A7-1, the saturated peat method always had the lowest amount of added water.

A-7.4 Discussion

Conductivity is "a numerical expression of the ability of an aqueous solution to carry an electrical current" (APHA et al. 1985). Pure water is a poor conductor, but added dissolved ions carry an electrical current, in approximate proportion to the ion concentration (Day et al. 1979). Temperature and low pH values influence conductivity measurements, but Sjörs (1952) calculations can correct for this. As conductivity is dependent on the ion concentration, differing proportions of fresh peat:distilled water would affect conductivity measurements.

In this experiment, both the saturated peat method and the 1:2 ratio method used similar amounts of water, although less water was always added following the saturated peat method. With the similar proportions of water, the corrected conductivity values were also similar. With the higher proportion of water in the 1:10 ratio method, ion concentrations were diluted, and lower measured conductivity values were the result. The conductivity values were on average 4 times lower in concentration compared to the 1:2 ratio method, similar to the increase in water. The greater amount of added water also reduced the variation in measured conductivity values, as shown by the smaller standard deviation values.

A-7.5 Conclusions

The three peat conductivity methods used in Chapter 2 differed in soil/solution ratios. To convert between the saturated peat and 1:2 methods, and the 1:10 method the following formulas are proposed:

Corrected conductivity$_{1:10}$=Corrected conductivity$_{\mathrm{Sat}}$ / 4

Corrected conductivity$_{1:10}$=Corrected conductivity$_{1:2}$ / 4

A-7.6 References

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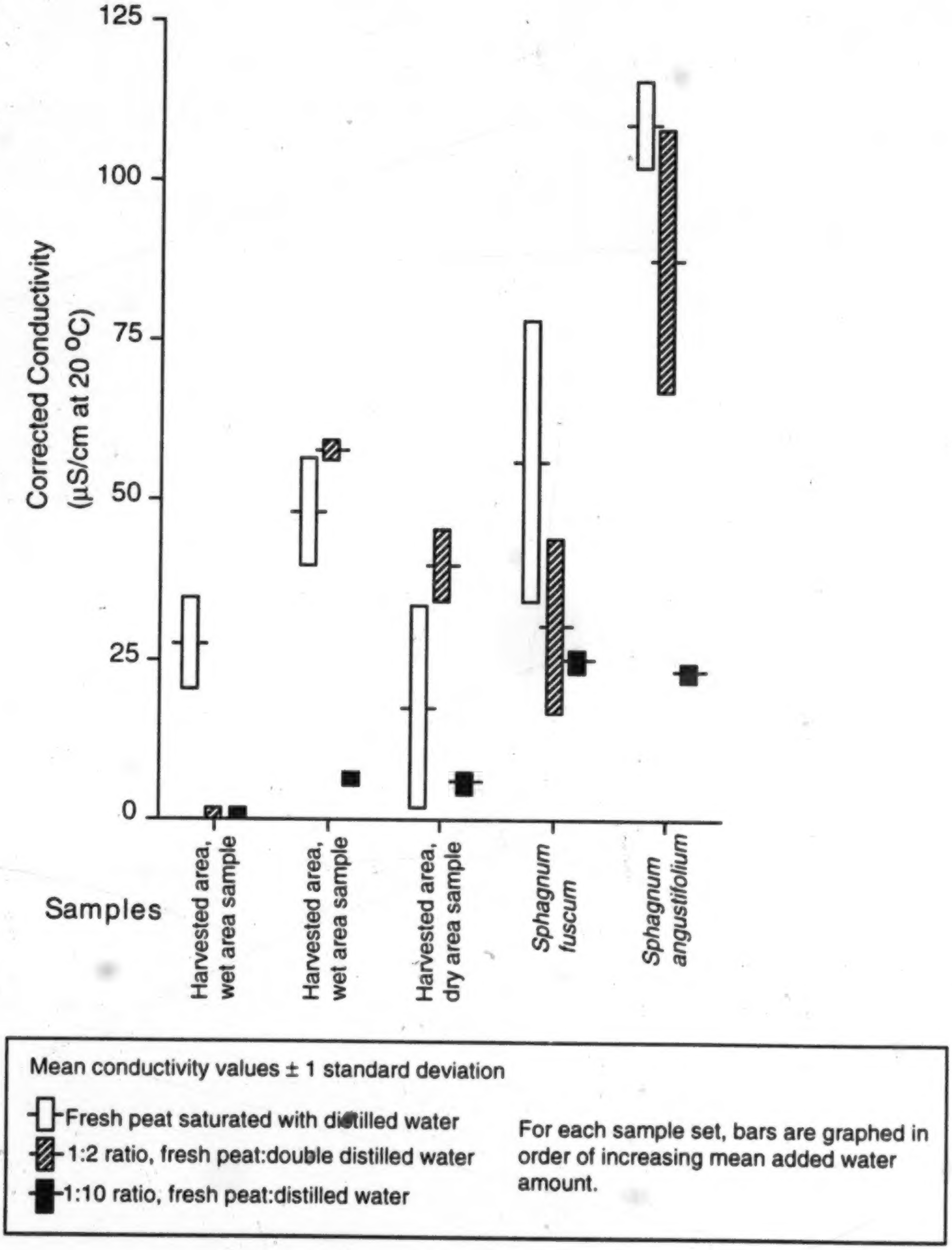

Figure A7-1. Results of three peat conductivity methods.
Mean corrected conductivity results (± 1 standard deviation) for three methods with five different peat samples. See Appendix 7 for more details.

Appendix 8.

Means (and ranges) of exchangeable cation data of the central Québec harvested area

	central Québec 1992 values ammonium acetate methods	central Québec 1993 values saturated media filtrate methods	central Québec 1992/1993 as listed in Table 2-4
n	9	7	16
Na (mg/kg)	53 (19-93)	188 (130-250)	112 (19-250)
K (mg/kg)	95 (36-191)	194 (160-260)	138 (36-260)
Ca (mg/kg)	1191 (807-1833)	783 (700-860)	1007 (700-1833)
Mg (mg/kg)	193 (136-253)	201 (150-250)	197 (136-253)